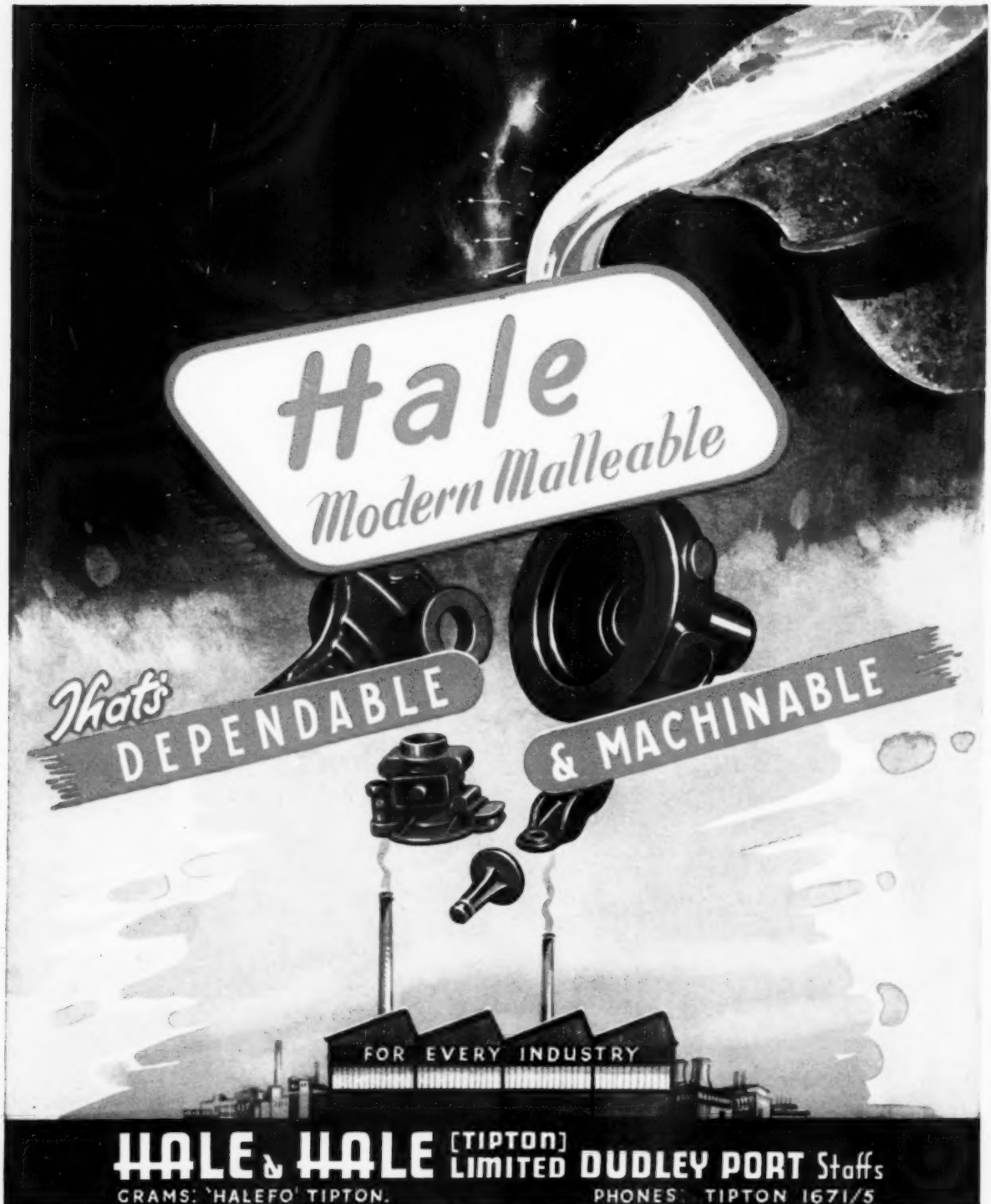
METALLURGIA

THE BRITISH JOURNAL OF METALS

Vol. 59 No. 354 APRIL, 1959 Monthly: Two Shillings and Sixpence



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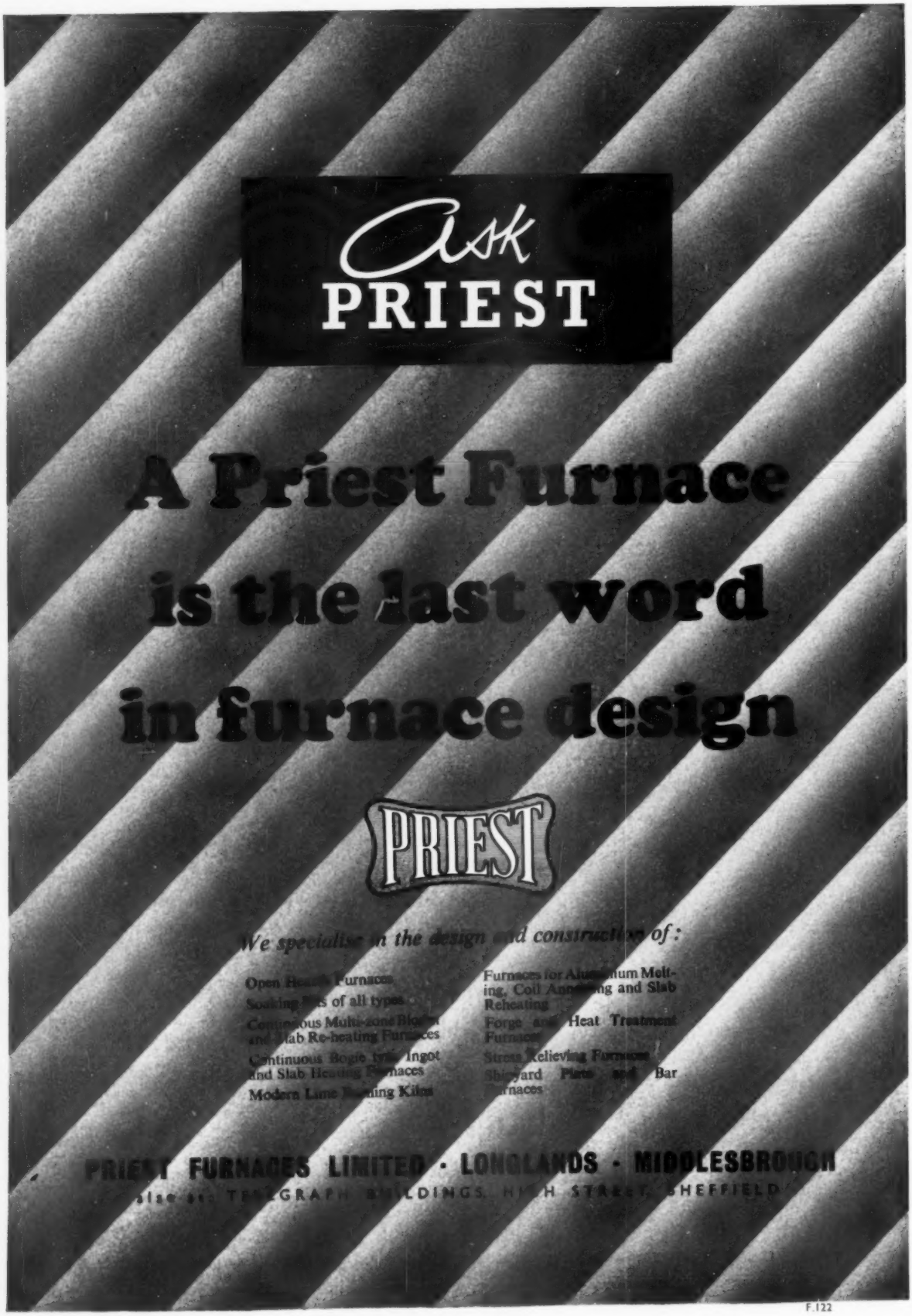
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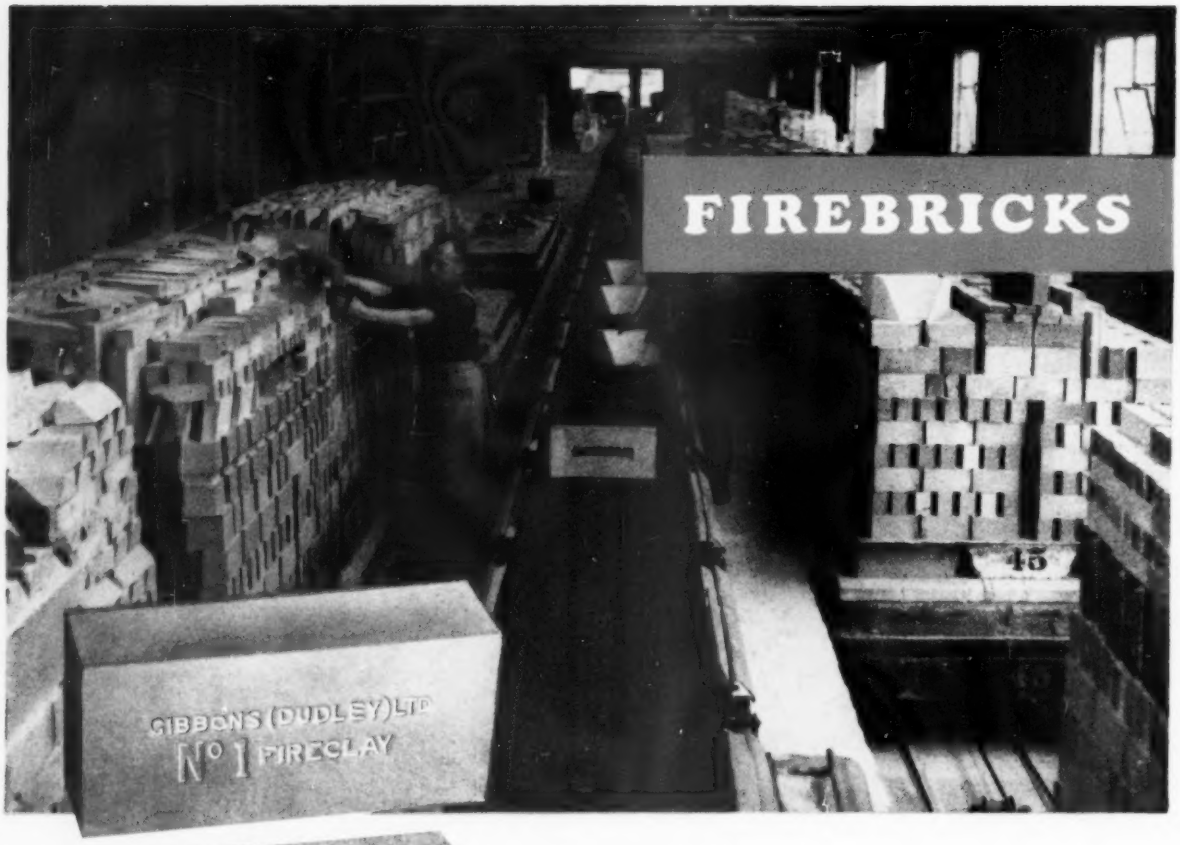

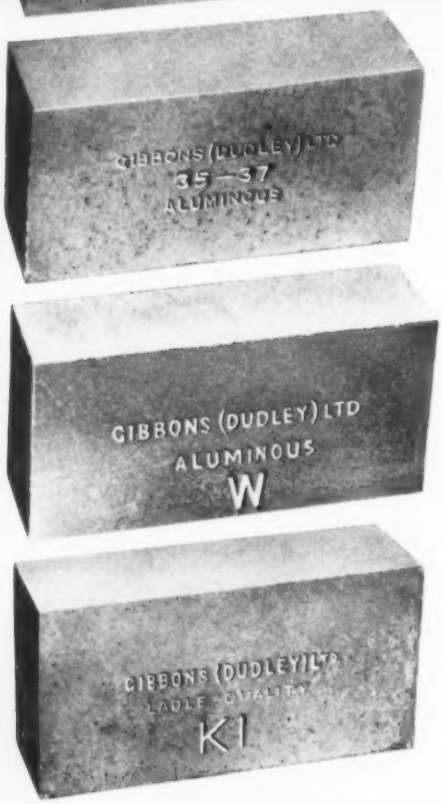

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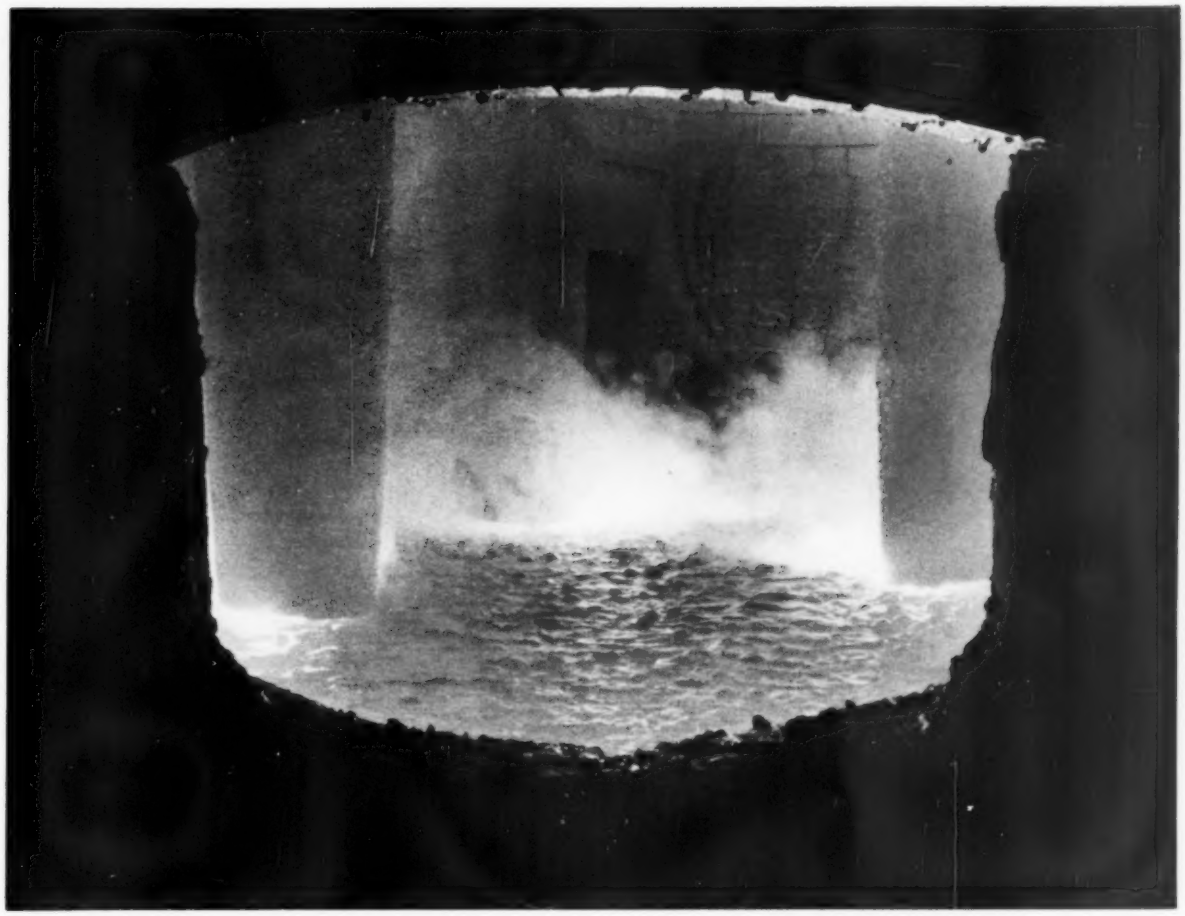

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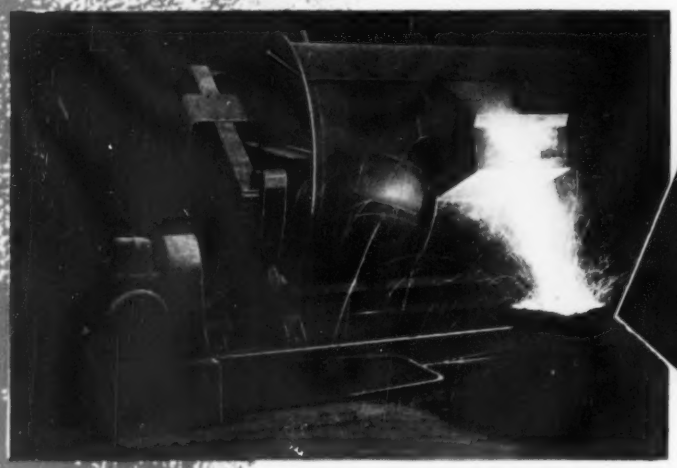

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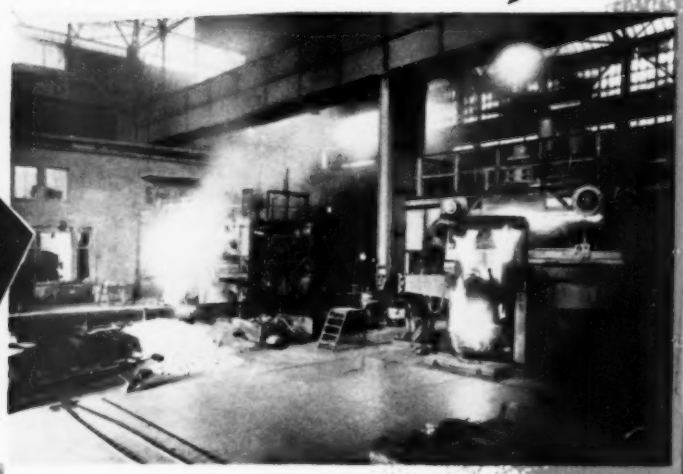

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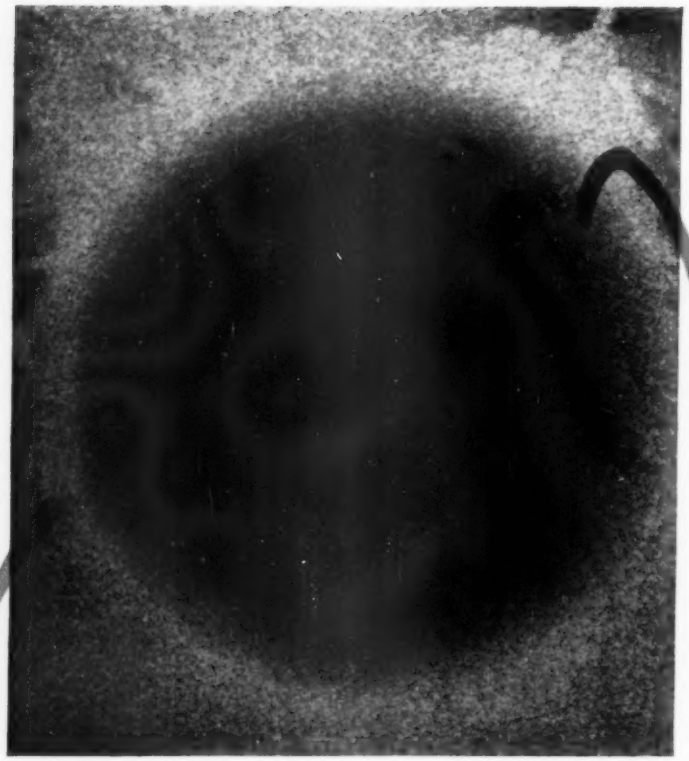

2mm + 2mm light alloy spot weld, magnified 7 times

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No. 17	Dry	+1750°C	Hydraulic	1200°C	1700°C	160
No. 18	Dry	+1750°C	Hydraulic	1200°C	1800°C	160
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Gas Consumption, 200 cu. ft. per hour maximum.

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Suitable for temperatures up to 900° C.

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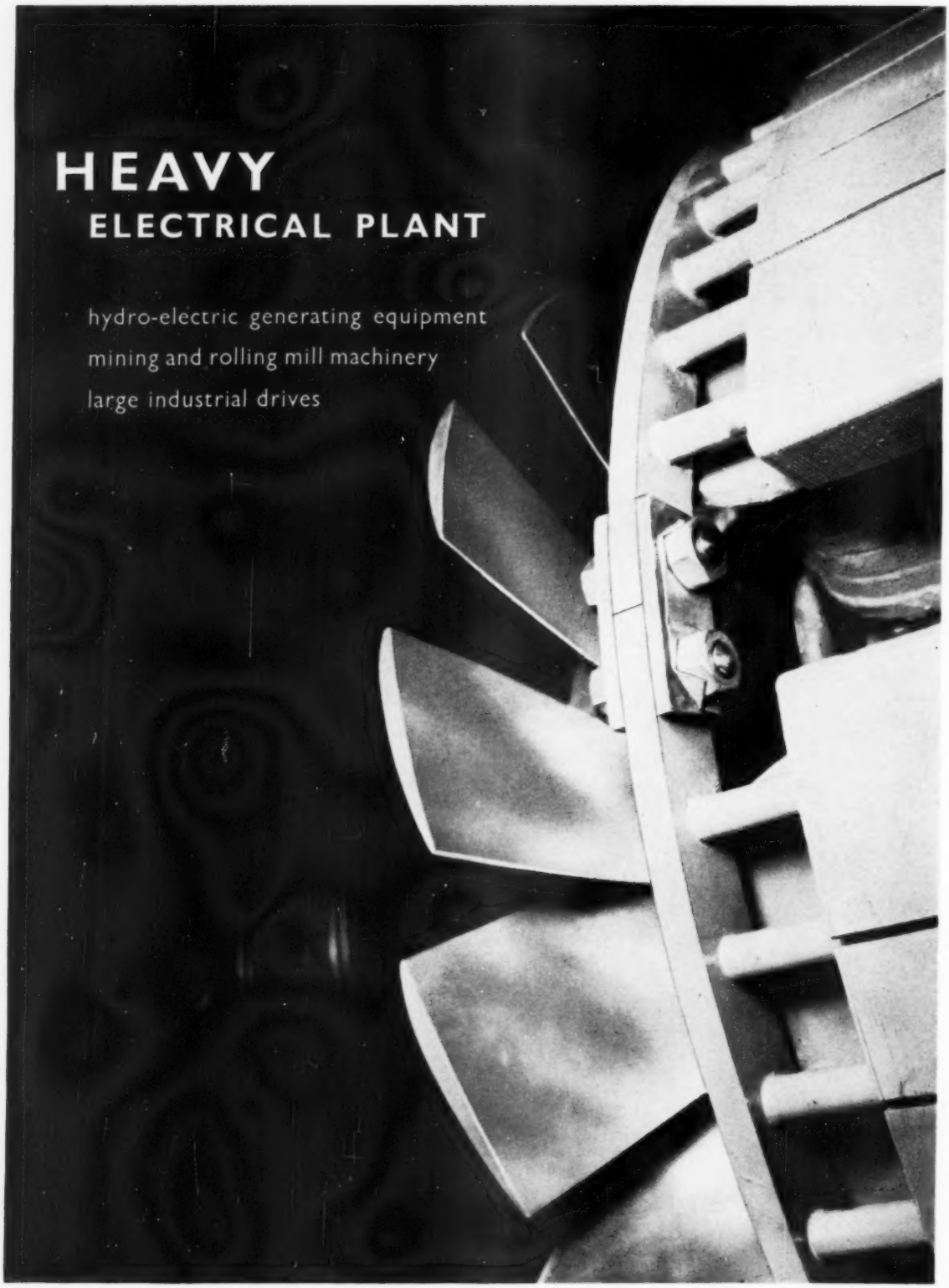

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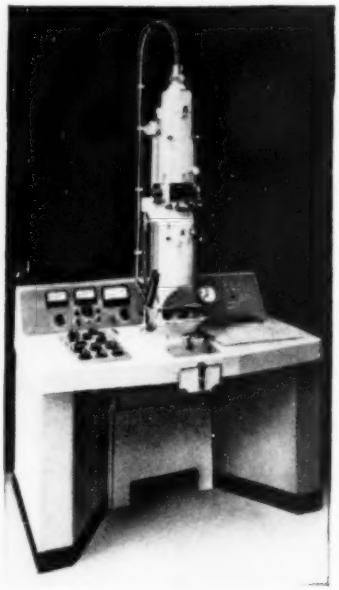

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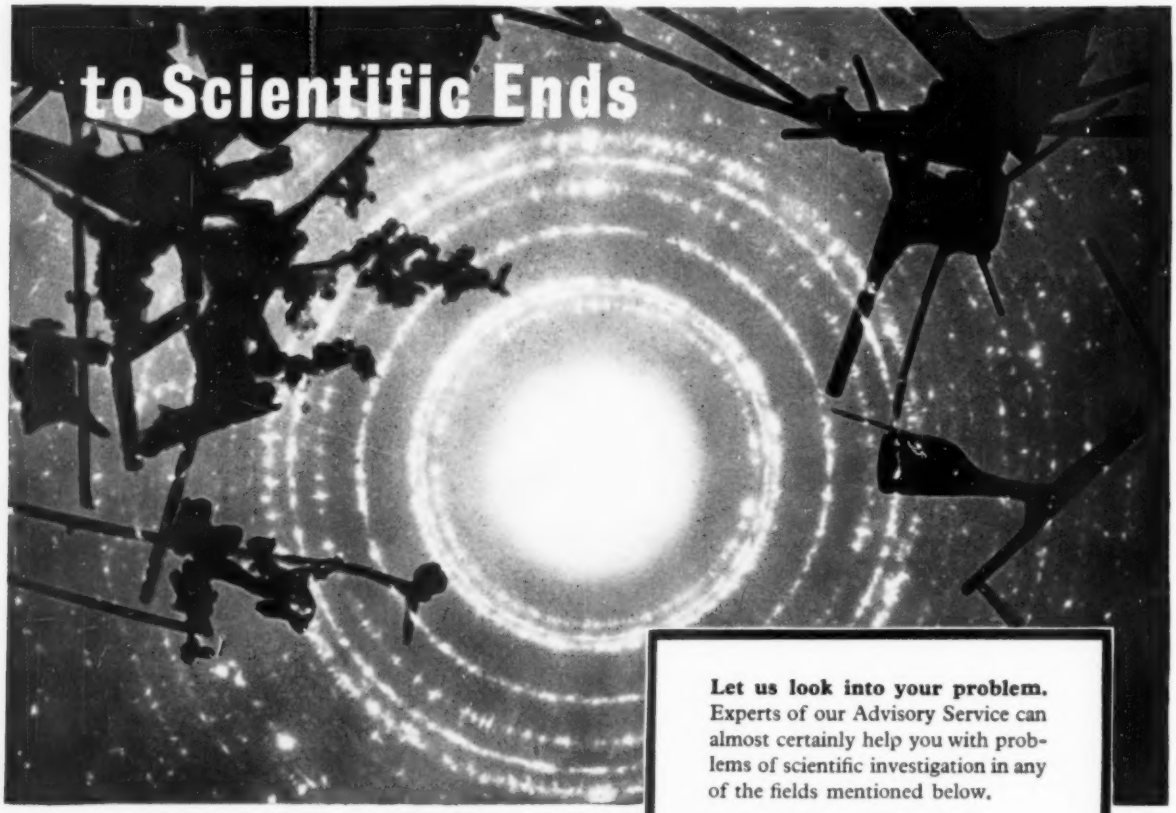

Information on crystal structure, particle size and shape. Illustration shows diffraction pattern of zinc oxide smoke superimposed on its electron micrograph.

Let us look into your problem. Experts of our Advisory Service can almost certainly help you with problems of scientific investigation in any of the fields mentioned below.

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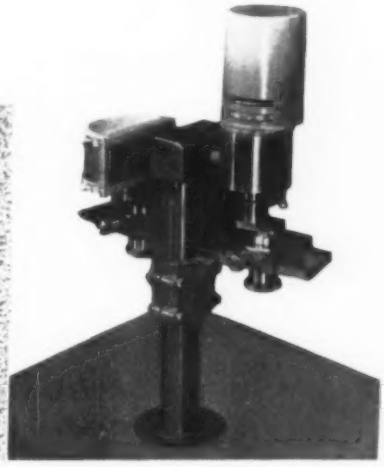

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The Microfocus Generator gives an intense line or spot focus for X-ray diffraction work or microradiography. Because of the high intensity of its focus, the Microfocus shortens exposures by as much as seven times.

X-ray diffraction apparatus

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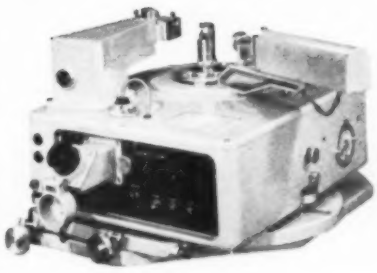
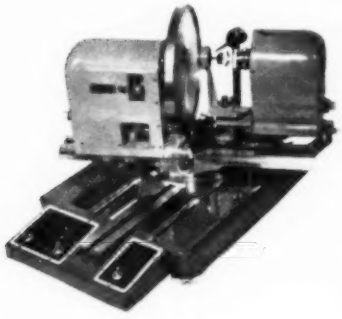
The Retigraph is made by Enraf-Nonius of Delft.





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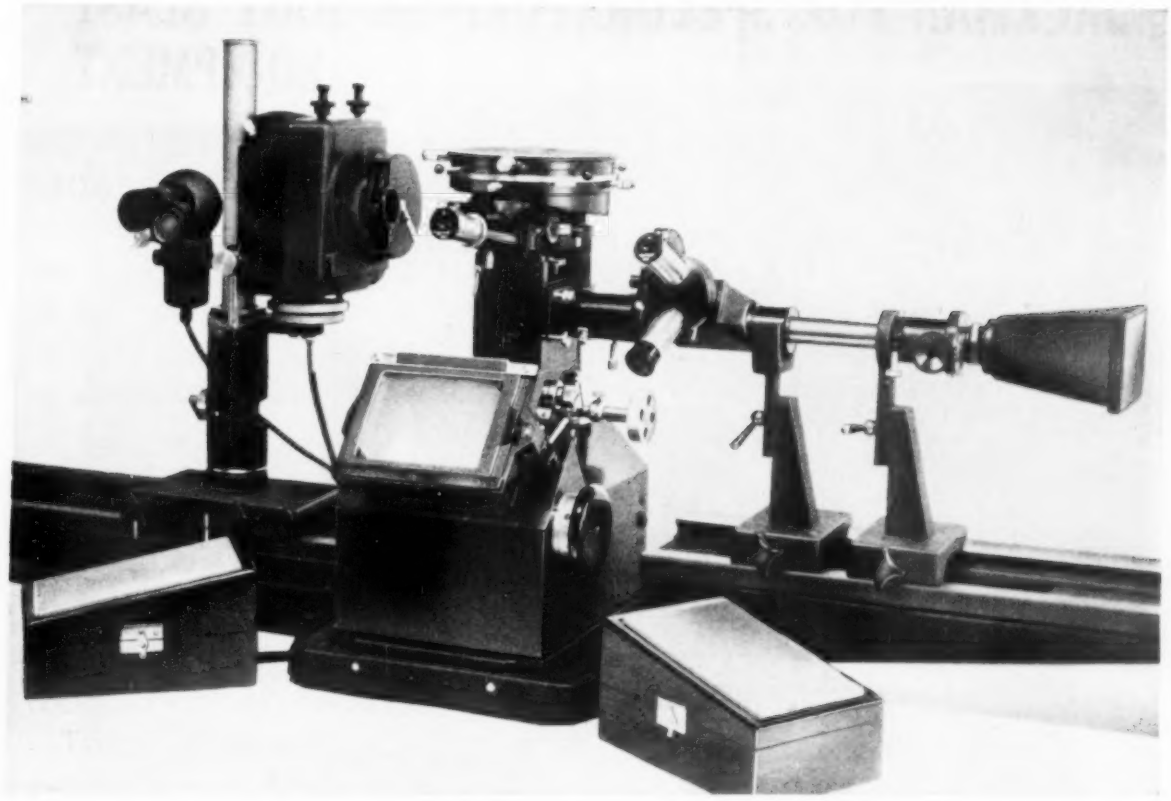

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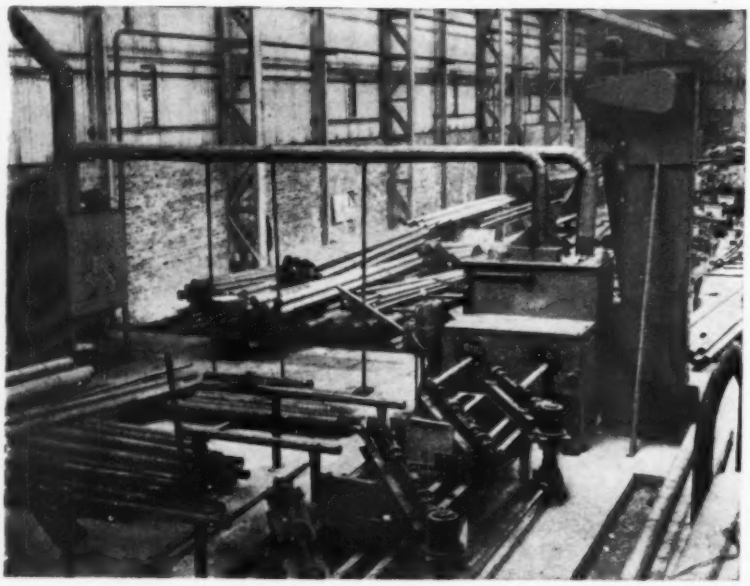

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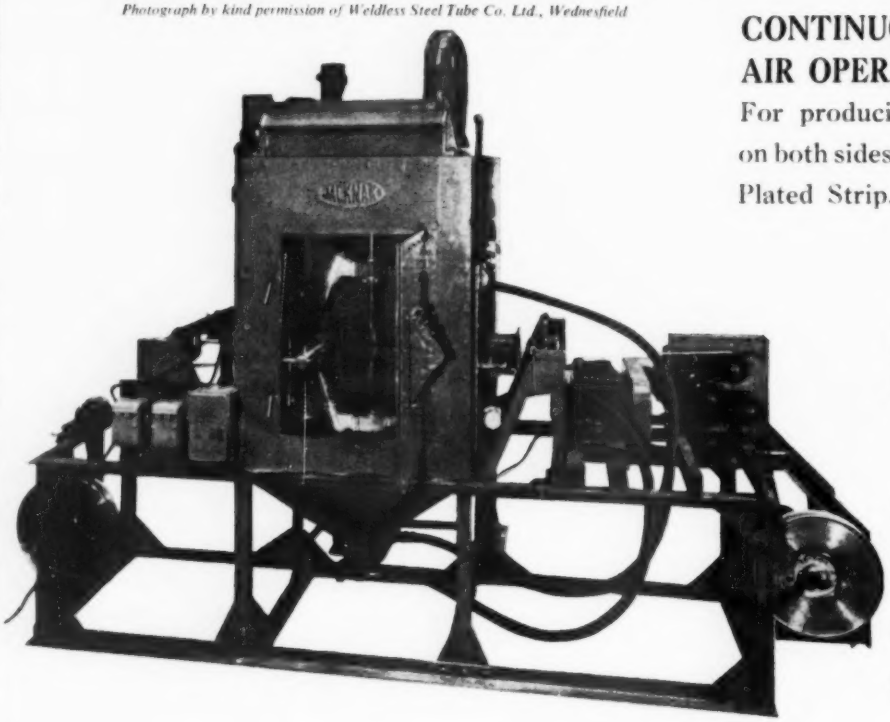

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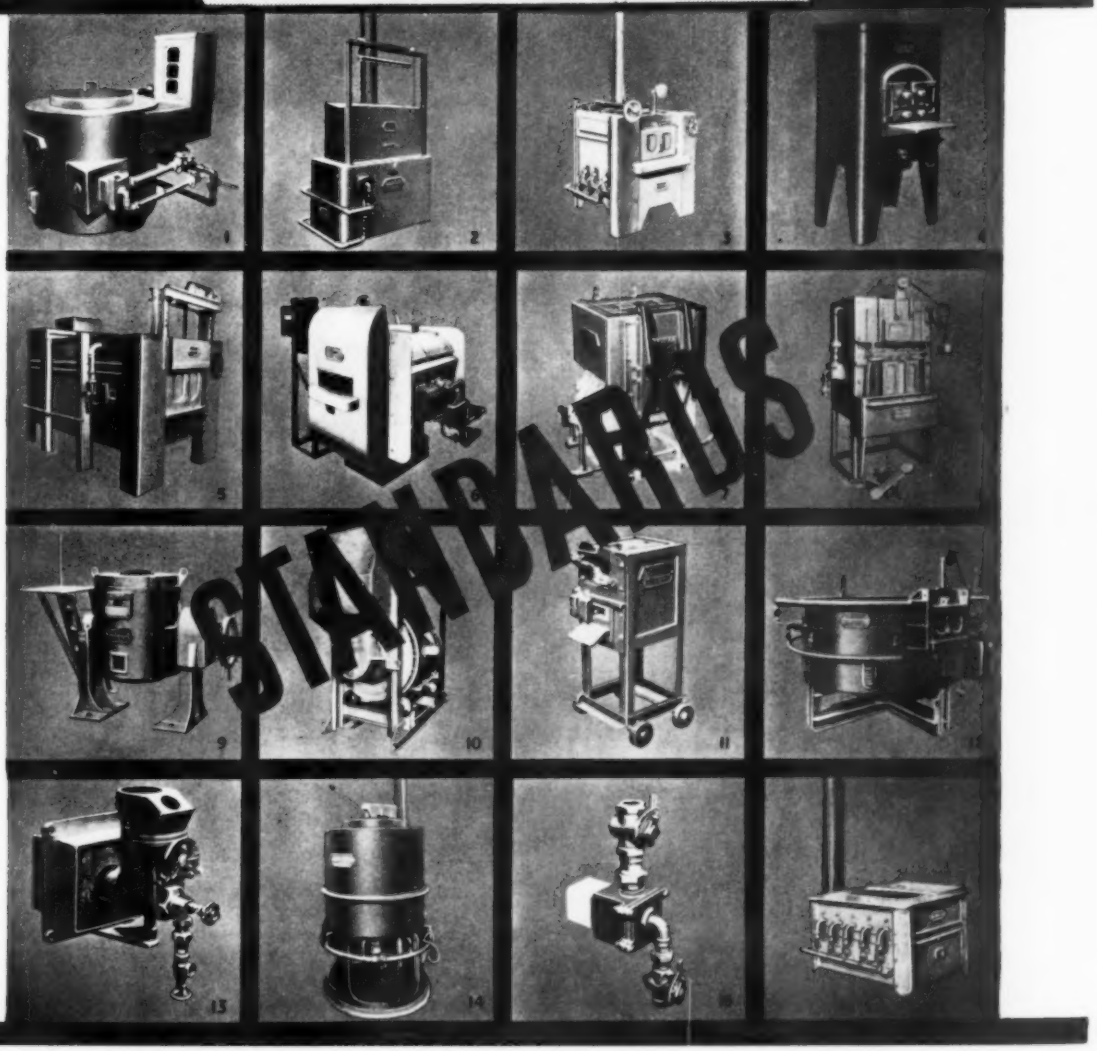

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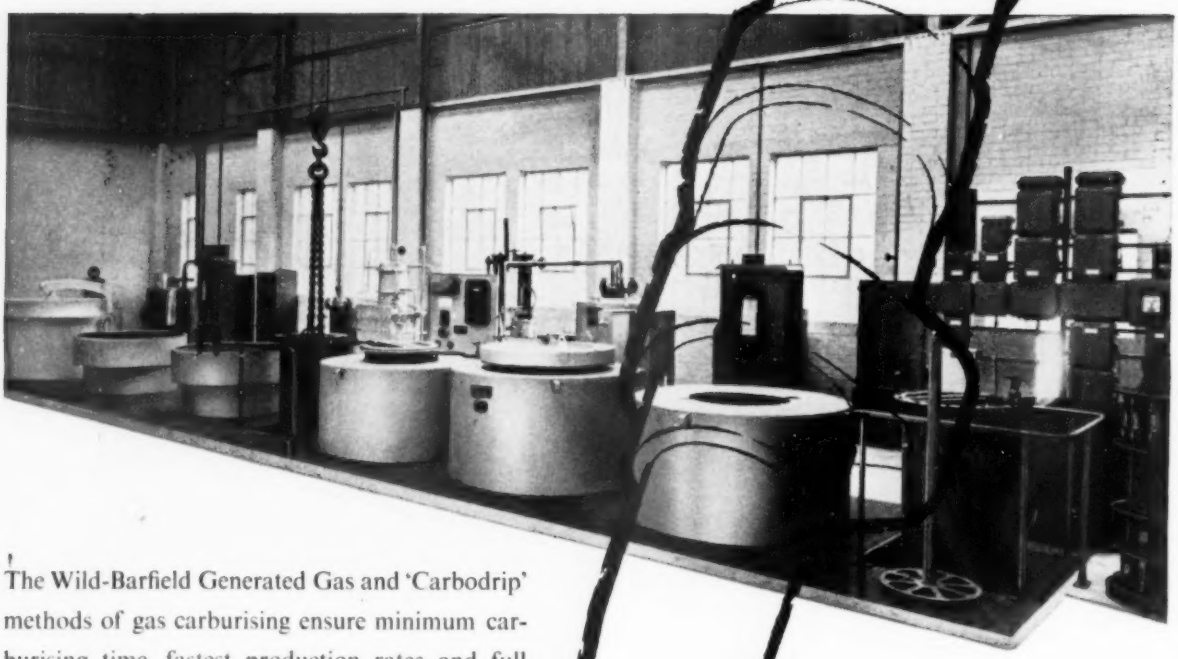

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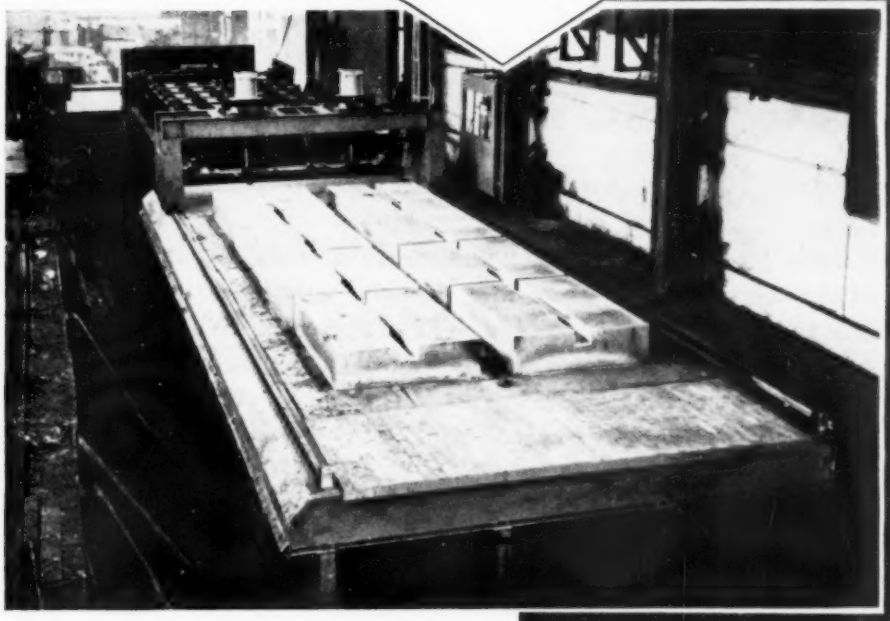

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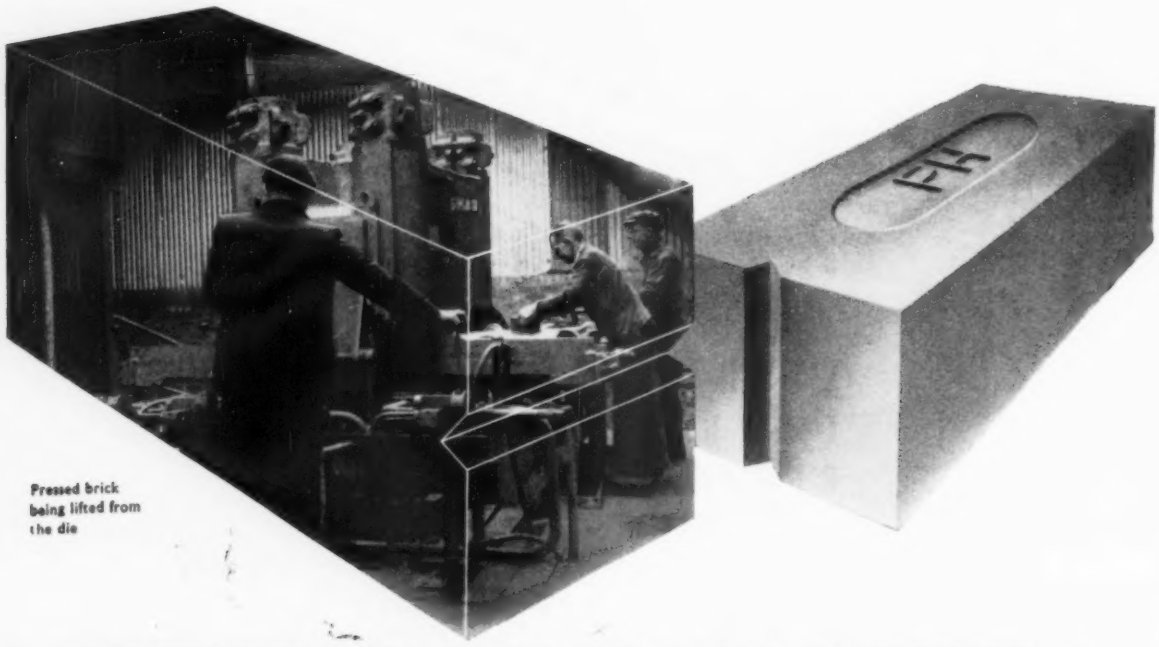

Pressed brick being lifted from the die

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Refractory bricks today must be absolutely accurate in size and shape. These qualities, combined with unerring consistency in texture and performance are achieved by Pickford Holland through the medium of the most modern plant and equipment.

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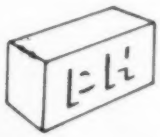

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WB74

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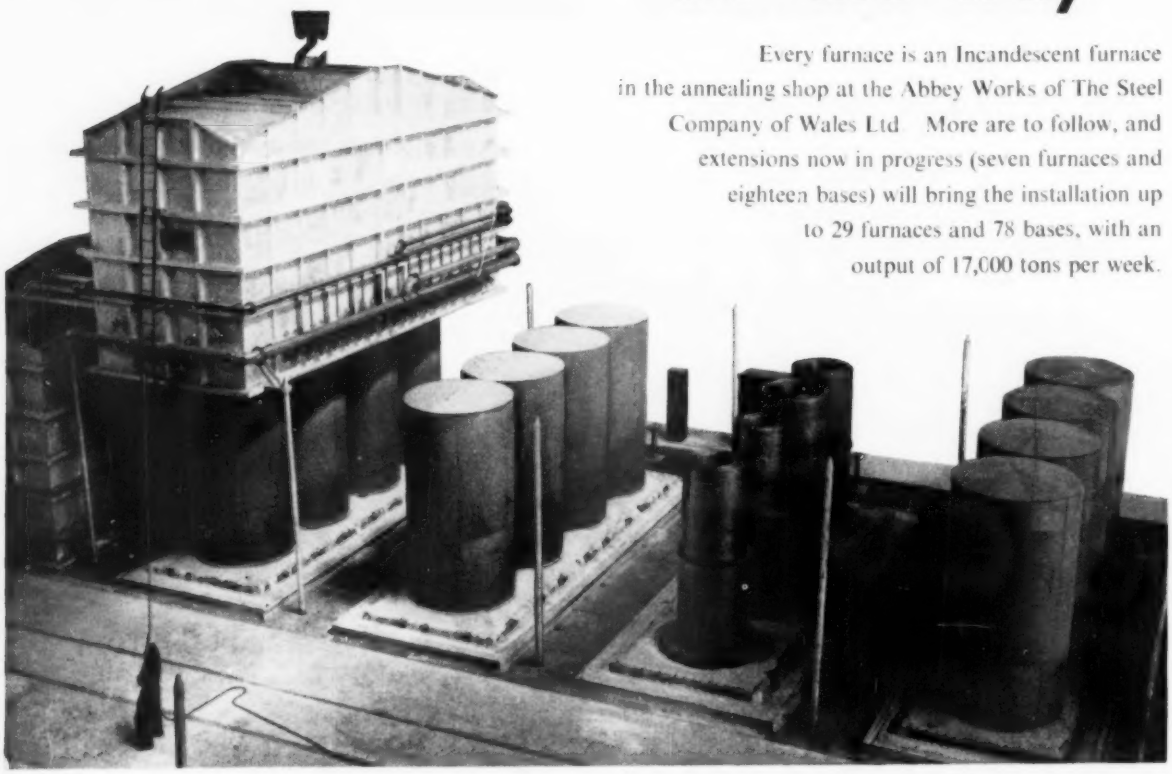

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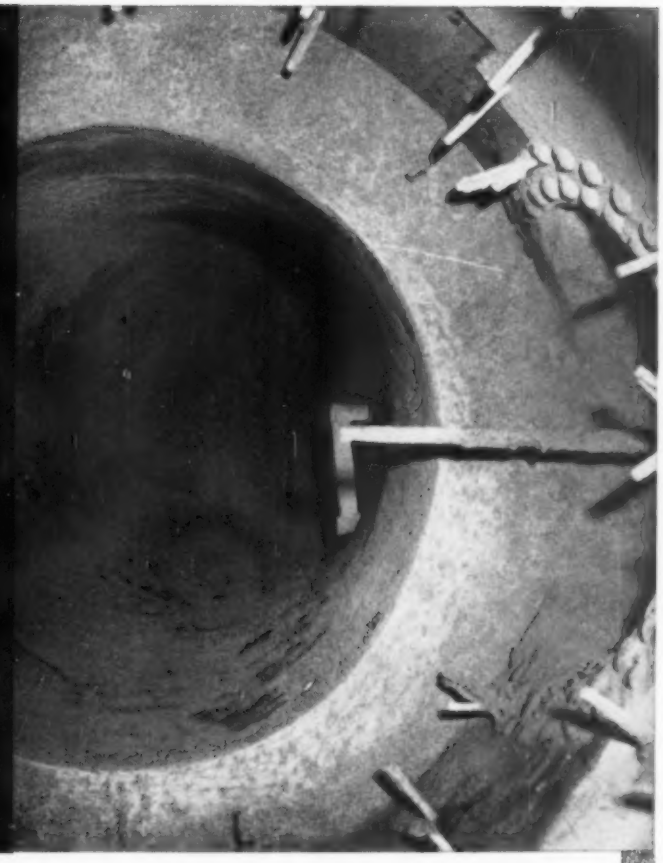

Bustle main of Queen Victoria Blast Furnace showing 'gunned' lining in Tri-Mor Dense 'Guncrete'. (Inside diameter of shell 5 feet. Thickness of 'Guncrete' lining 9 inches).
Photograph by courtesy of the Appleby-Frodingham Steel Co. (Branch of the United Steel Companies Ltd.).

TRI-MOR GRADES

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A medium texture refractory having negligible shrinkage up to 1,350 C. Suitable for casting special shapes or for monolithic structures. Limiting service temperature 1,350 C.

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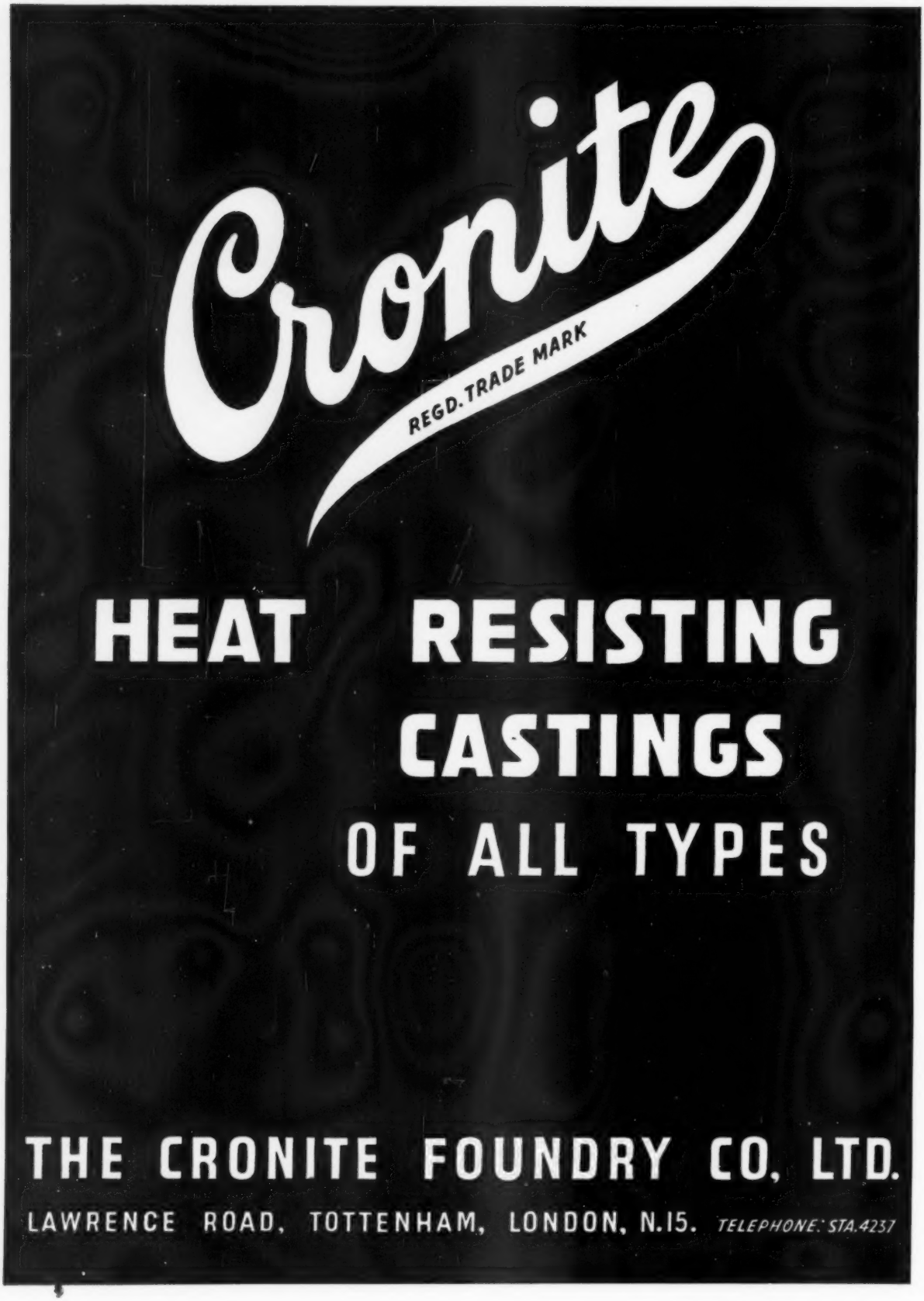
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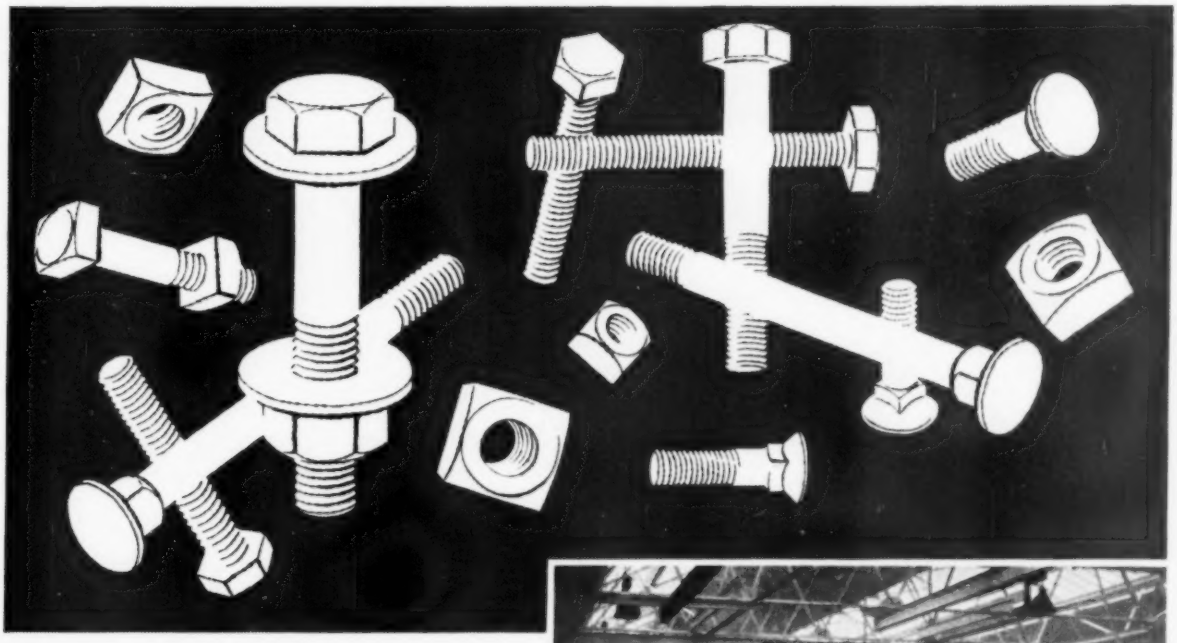

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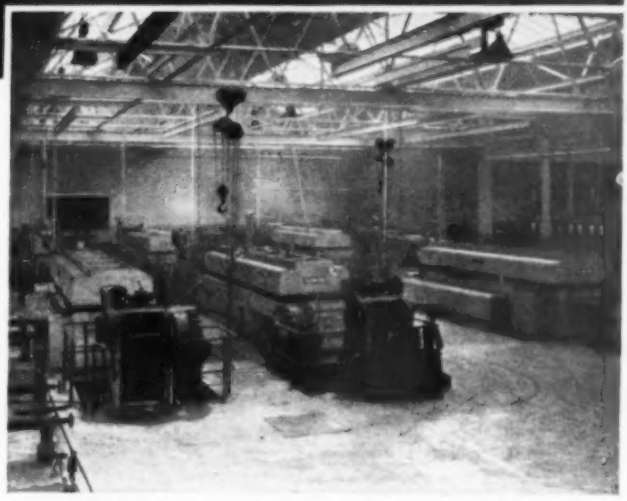

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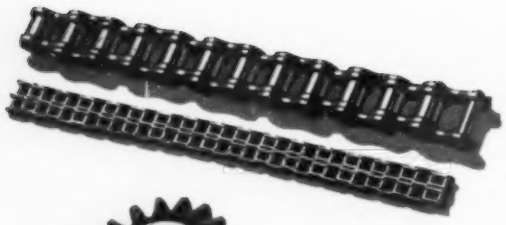
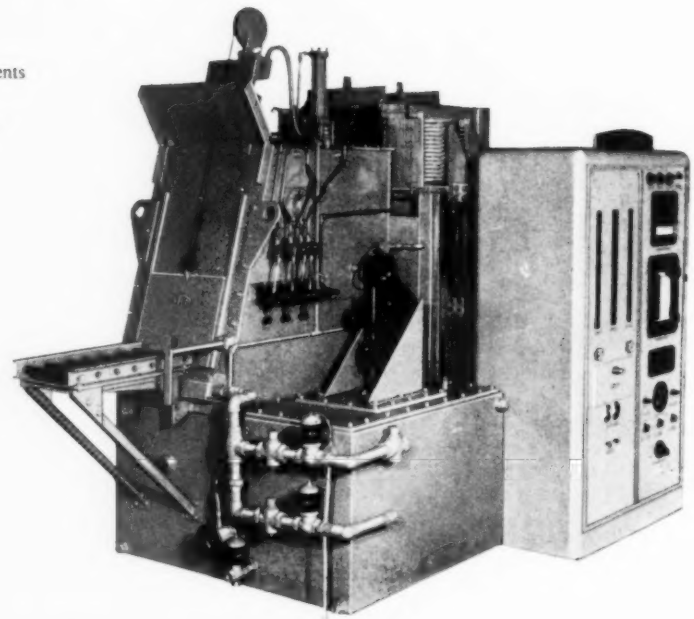


Roller chain parts carbonitrided in Efco-Lindberg Carbonitrider by Morse Chain division of Borg-Warner Ltd

Ford motor gear parts carbonitrided in Efco-Lindberg Carbonitrider

Wear resistant parts like these *are Carbonitrided in EFCO Furnaces*

Cash register, roller chain, and motor car manufacturers use Efco furnaces for carbonitriding components that must withstand impact and wear. A typical Efco-Lindberg carbonitrider is the standard CT-122410-A3 furnace illustrated. This is heated by the new Corrtherm electrical elements located in the side walls, the current being supplied through aluminium busbars from a special transformer situated on the top of the furnace. The charge dimensions are 12 in. wide × 10 in. high × 24 in. long, and the output for straight hardening is about 100 lb. per hour. Standard sizes are available up to 24 in. wide × 18 in. high × 48 in. long.



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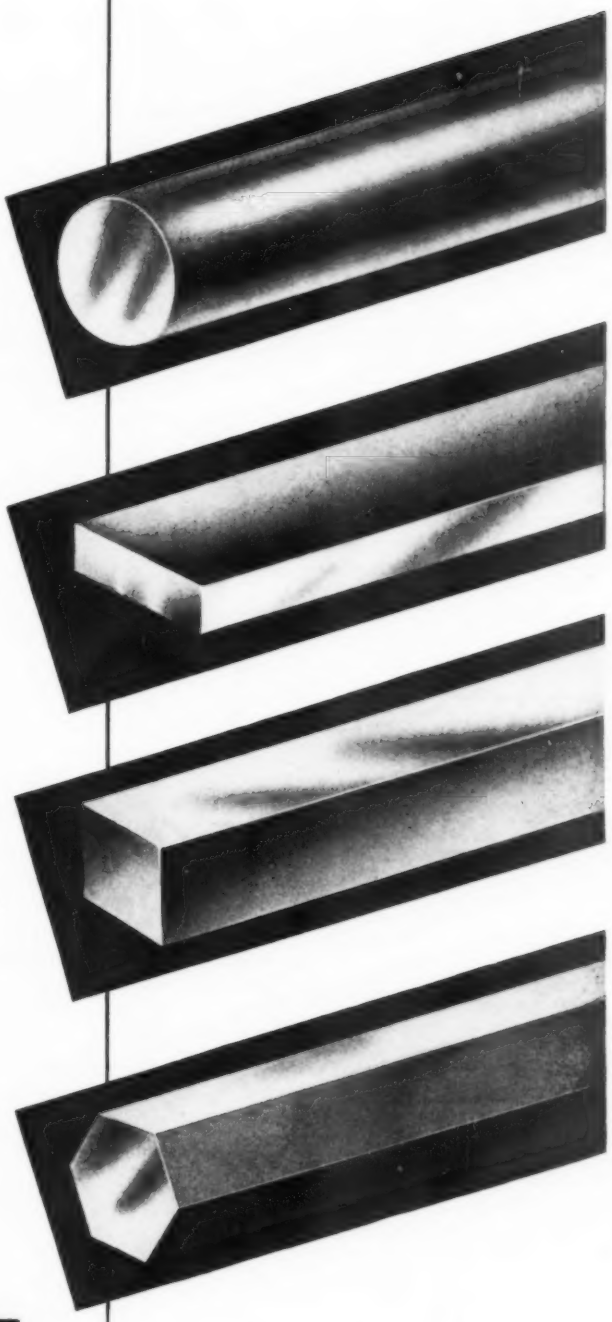

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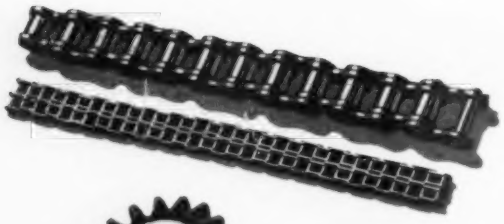

Roller chain parts carbonitrided in Efco-Lindberg Carbonitrider by Morse Chain division of Borg-Warner Ltd

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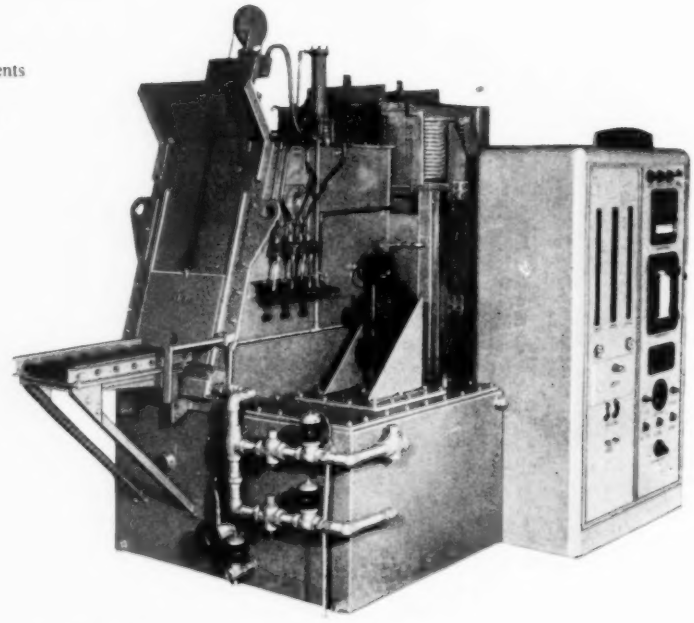

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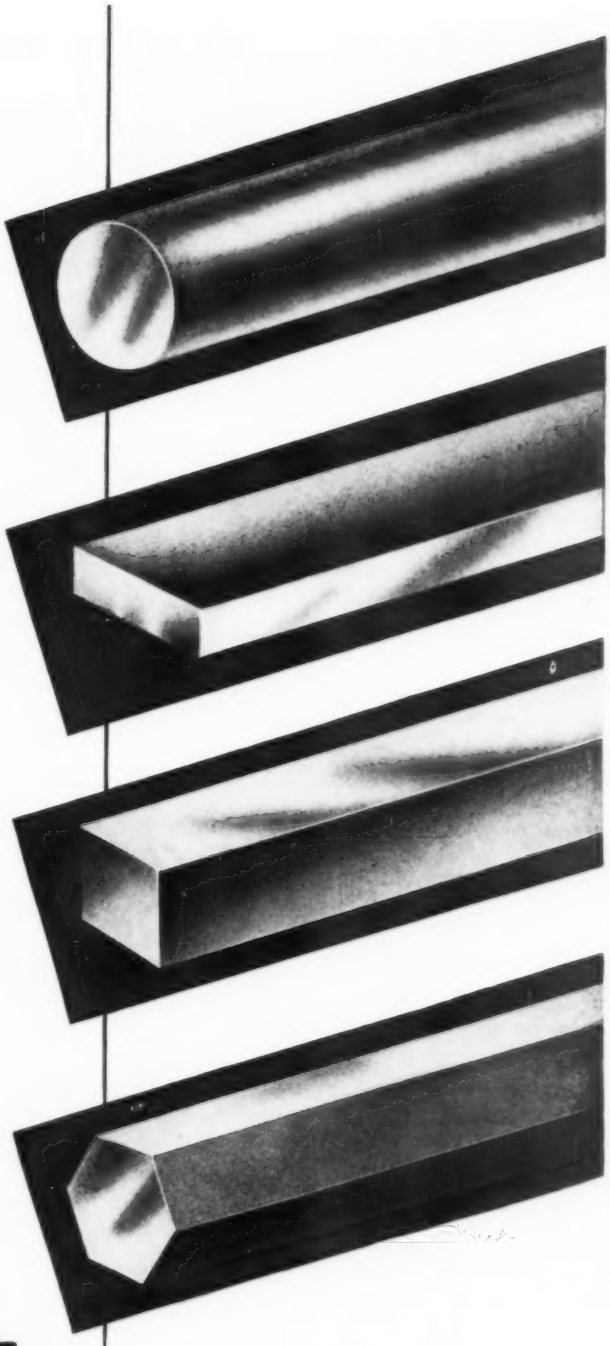

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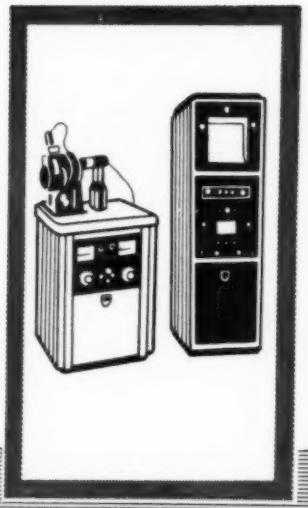

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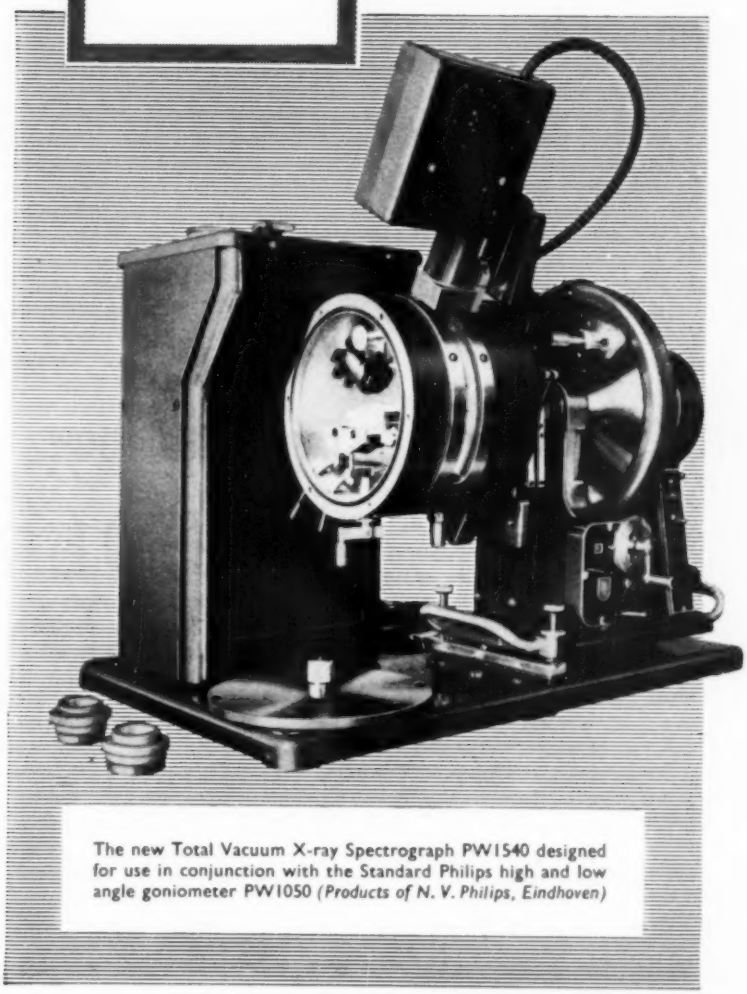

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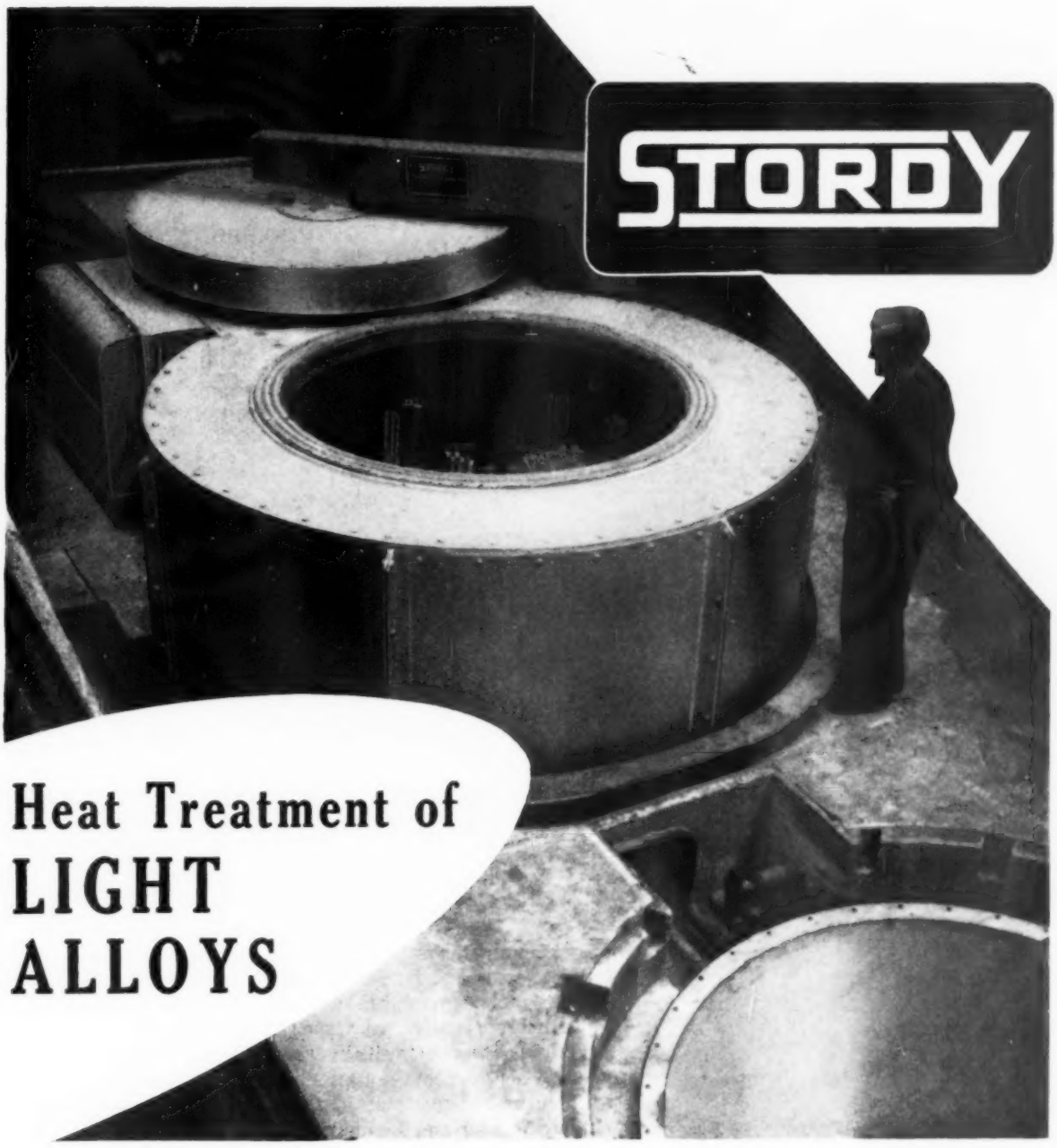

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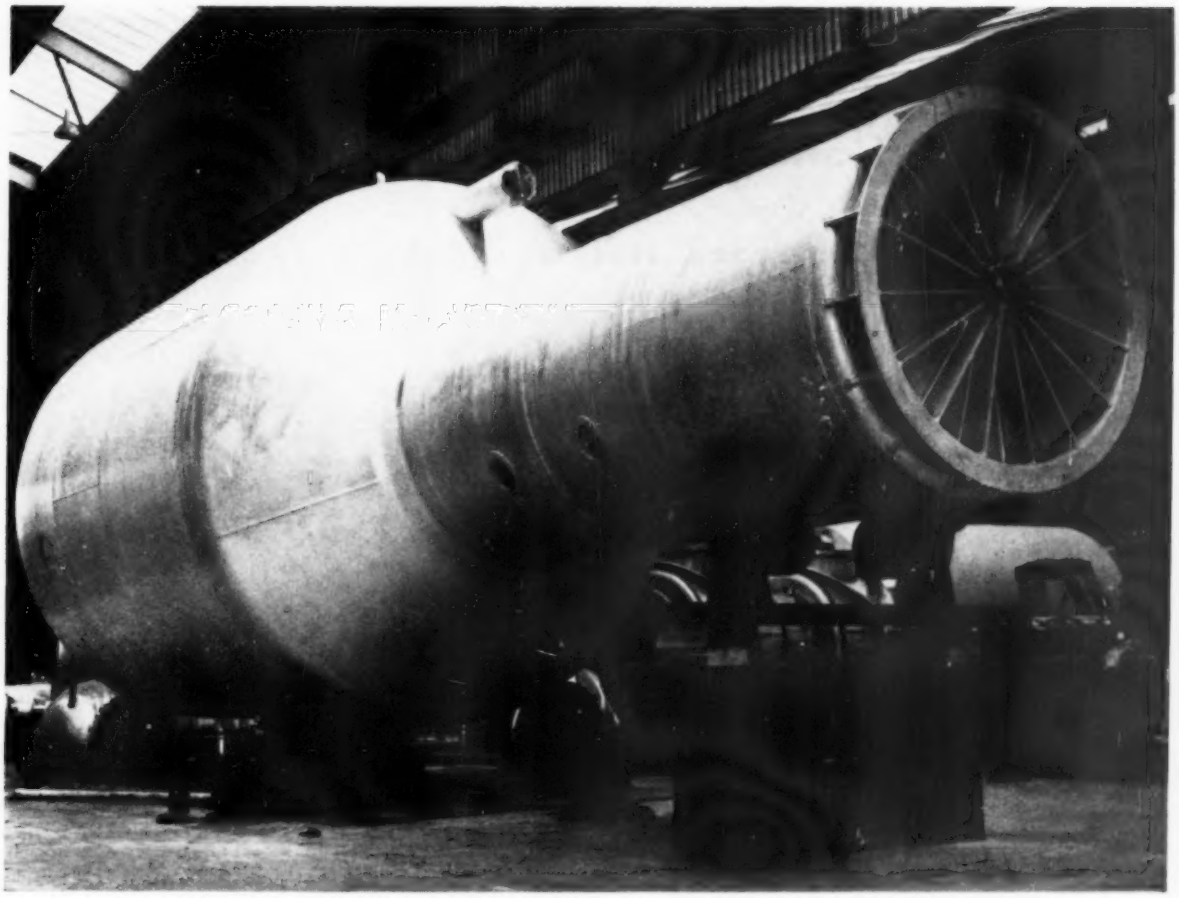

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This Core Tank for a Merlin-type Swimming Pool Reactor was produced by The A.P.V. Co. Ltd, using BA 99.5% purity aluminium plate, inert-gas welded.

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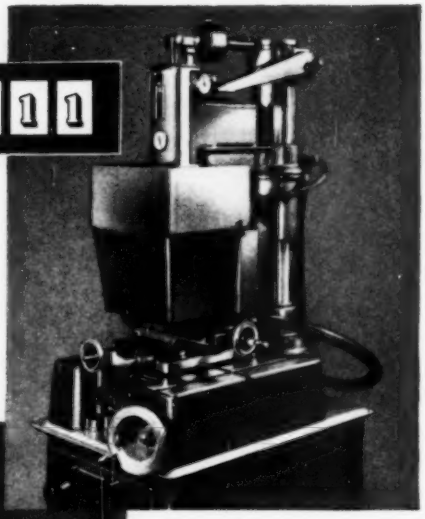

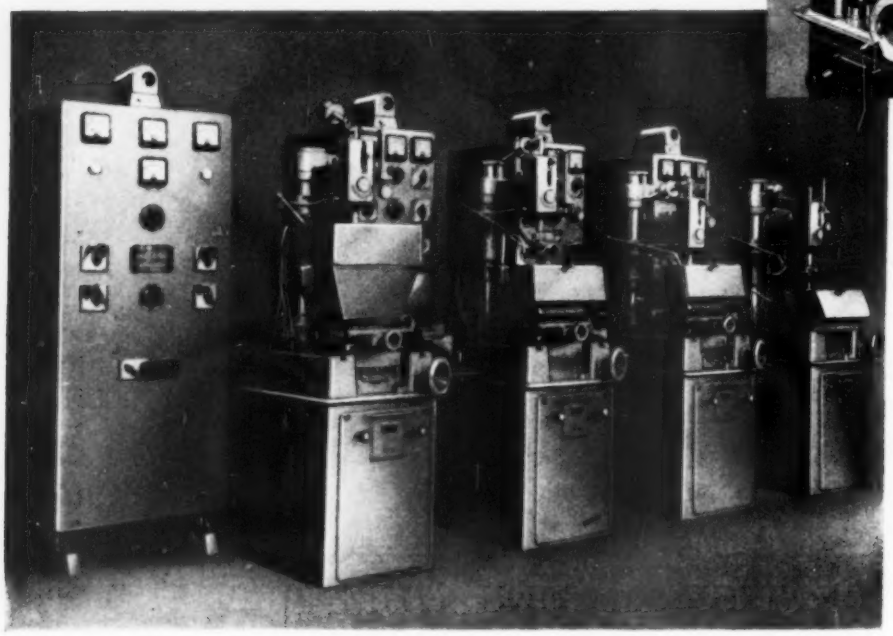

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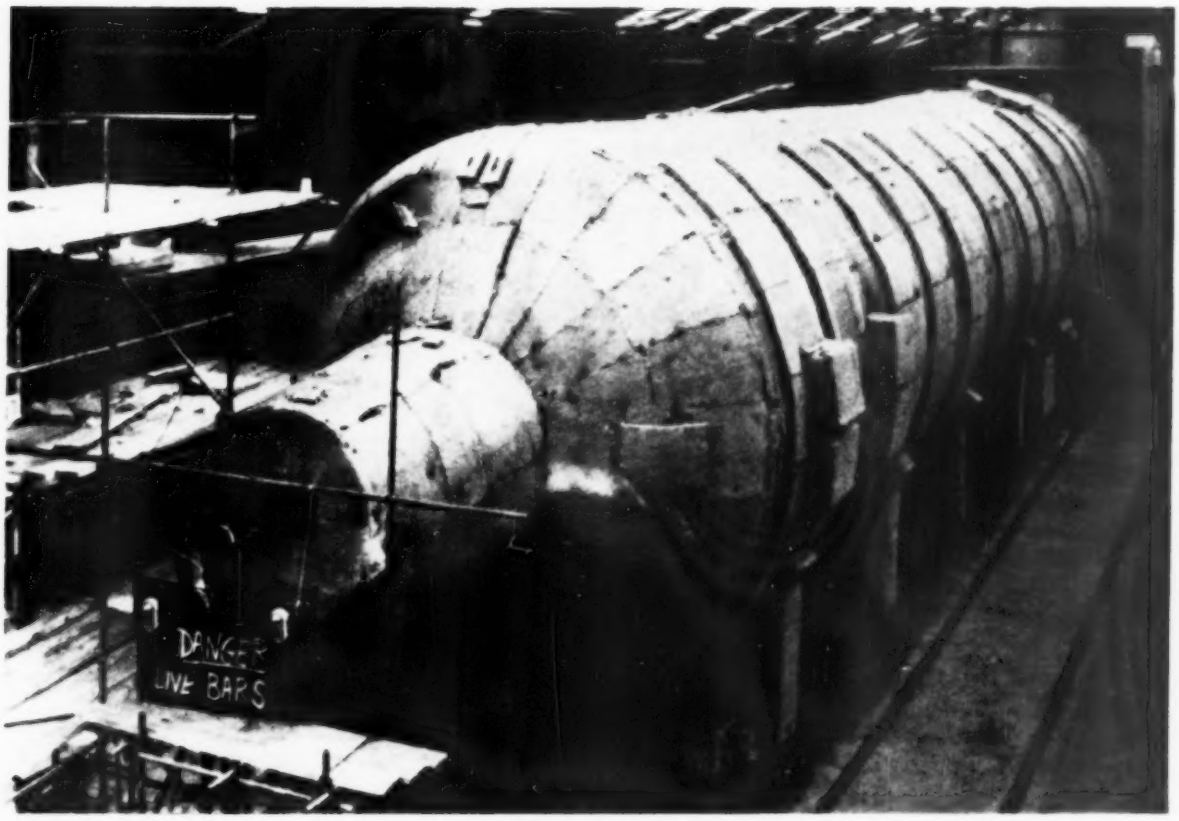

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360 pages *ILLUSTRATED* **4/6** *NET (by post* **5/3***)*

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A Review of Progress in the Steam Cycle and the performance of Steam Turbine Plants
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Toothed Gearing
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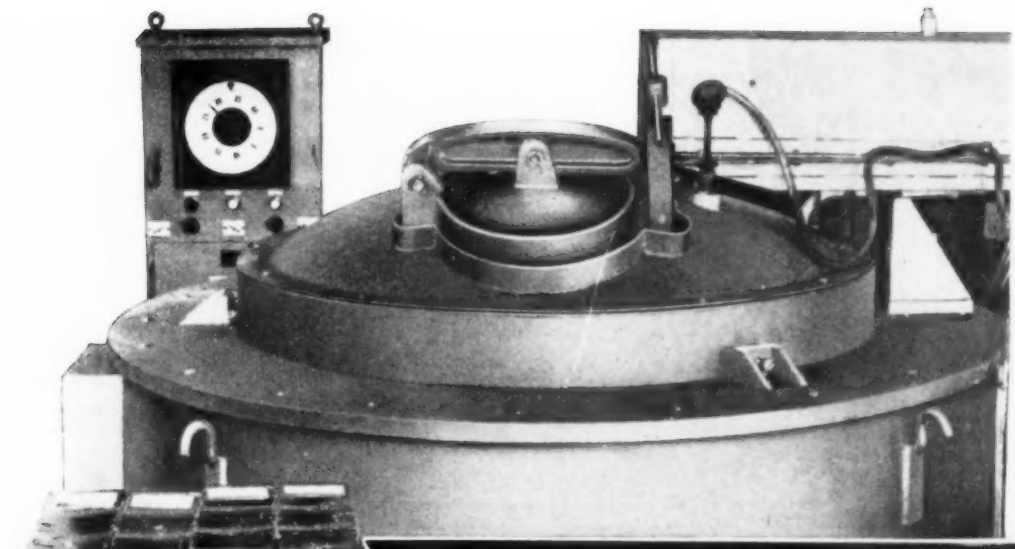

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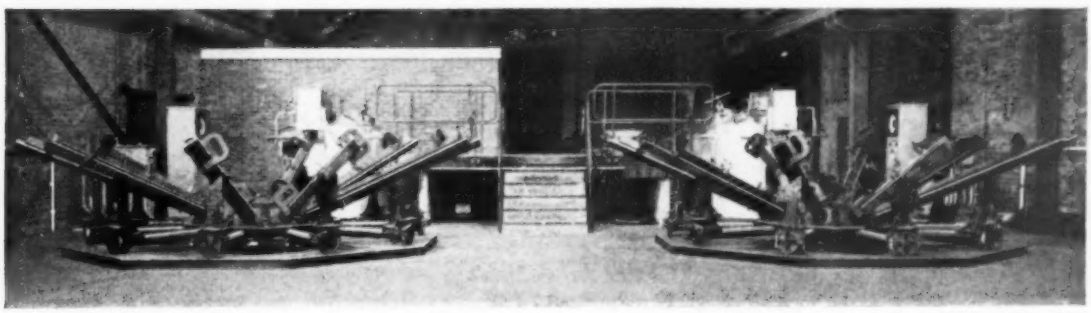

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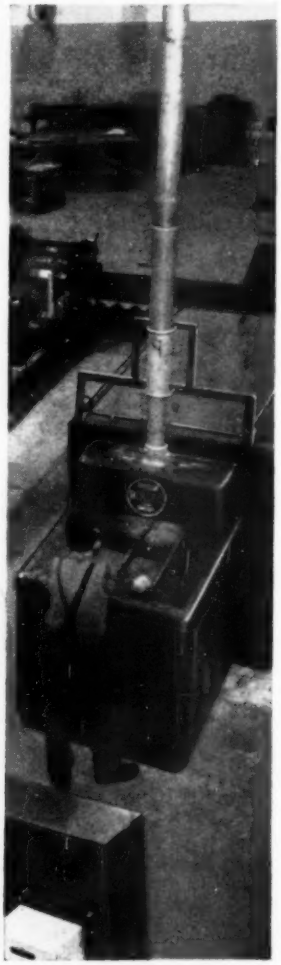

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THE BRITISH JOURNAL OF METALS
INCORPORATING THE METALLURGICAL ENGINEER

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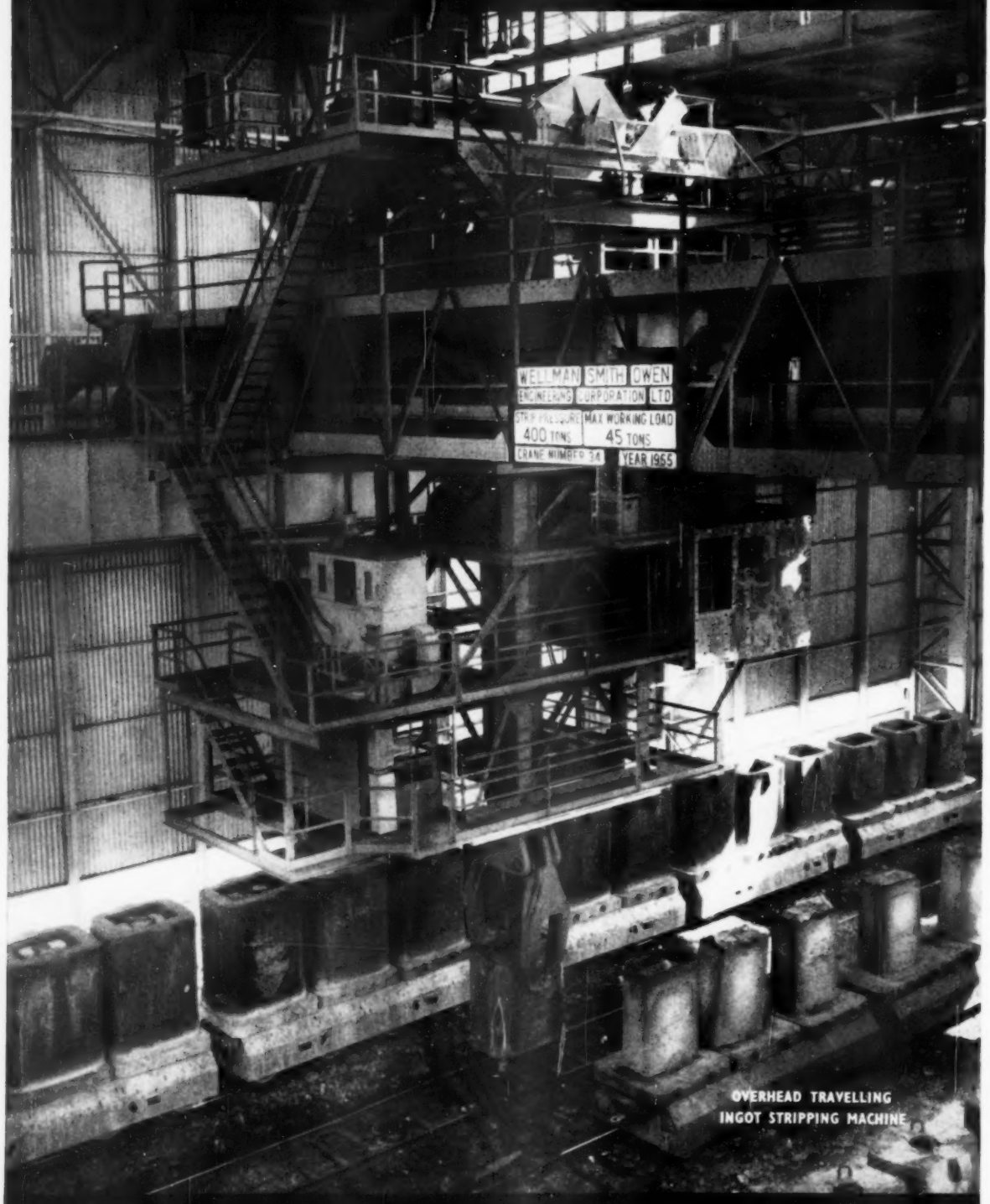

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METALLURGIA

THE BRITISH JOURNAL OF METALS

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APRIL, 1959 Vol. LIX. No. 354

The Technologist and Management

ALTHOUGH much of the talk about wages and profits seems to ignore the fact, the continued prosperity of this country and the maintenance of our standard of living depend as much as ever they did on our export trade, which relies mainly on those industries in which rapid technological progress is being made. For our export drive to be successful, therefore, it is essential that we should be in the forefront of these advances, and this calls for an adequate supply of scientists and technologists, the former to carry out the research which will expand the frontiers of our scientific knowledge, and in so doing may reveal secrets of nature on which important developments may be based, and the latter to ensure that there is no delay in exploiting these discoveries and applying them on an industrial and commercial scale. Because of the importance of the technologist in this rôle, Lord Simon, Chairman of the Port of London Authority, told his audience at the first Hugh Macmillan Memorial Lecture to the Institution of Engineers and Shipbuilders in Scotland, that he is likely to find it difficult to enter the management field.

Before discussing the various factors involved, Lord Simon distinguished between the board of directors and the management, pointing out that the function of the board is to decide upon the policy of the company, and of the management to carry out that policy. It is essential of course that the two work closely together, and for that reason it is necessary that each should understand the difficulties of the other. The distinction having been made, it will be seen that the personal qualities which make for a good director are different from those needed in management. The attributes of the technologist are different again, so that the fact that a man is successful in the one sphere is no criterion that he will be in either of the others. On the other hand, the man who has made his mark as a technologist may prove equally effective in the fields of management or direction—as has been amply demonstrated in many instances.

Among the qualifications needed by the manager—whose main function is to weld all those working for the company into a team, and to organise their work in an economical and an efficient way—Lord Simon places first the ability to lead men and to control them without seeming to regiment them. Whilst experience can certainly help in this respect, inherent characteristics are of the utmost importance, and for this reason many believe that good managers are born, not made. Nevertheless, the future manager needs plenty of experience at lower levels in the art of management itself, in order to develop his potentialities in this field. Ideally, he should have departmental experience in as many as possible of the different sides of the business, as this will prove of inestimable value in his task of trying to unite the efforts of the various sections into an efficient whole.

What technical qualifications are required in a manager depends largely on the nature of the company's activities. He must, at least, have sufficient knowledge, not only of the technical processes themselves, but of the scientific basis on which they rest, to be able to understand the problems that are likely to arise, the way in which these problems can be met and overcome, and the direction in which progress and development is likely to lie. He must also be able to discuss these matters intelligently with the technical experts, and provided he does not imagine he knows more about it than they do, the wider his knowledge the better.

The technologist on entering industry has probably had a good scientific training, together with some experience of applied science in a technological or research institute. He now has to apply his mind to the problems of the industry and familiarise himself with techniques and processes which are new to him. Moreover, he must keep up to date with progress in his own and adjacent fields. All this is complementary to his principal job in research, development, production, etc. It will be obvious, therefore, that his time is pretty well filled without expansion according to Parkinson's Law—compression would be nearer the mark! In these circumstances it is difficult for the technologist to find time to acquire the wider experience necessary to make him a successful manager. This is particularly true in an industry in which the relevant technology is rapidly changing, because so much of the technologist's time must be spent in keeping himself up to date.

There is no fundamental reason why a man with a scientific or technological education should not prove just as good at controlling and leading men as anyone else. Furthermore, he should be at an advantage in certain aspects of management, in that his training should have taught him how to formulate his experience, how to analyse it in such a way as to separate constants and variables in the problems he has to face, and how to establish the relationship between the variable factors. In this way he is able to shorten the long road of experience. It does seem, however, that management is faced with a difficult problem if a member of its technical staff is considered a possible candidate for promotion on the management side. To enable him to get some departmental experience in other aspects of the business, and give him early experience in management itself, involves taking him away from his technical duties. If technologists were ten a penny this step would be easy to take, but in the circumstances prevailing today it calls for a decision of major importance, because for quite a time his services will be less valuable to the company than when he was on the technical side, and although—if he makes good—his early training and experience will increase his value as a manager, the further development of his talents as a technologist will almost certainly have been sacrificed. The decision is not an easy one to make.

Scrap Exports

It is estimated that from September last year to the 7th March 1959, when the export licensing arrangements expired, some 400,000-500,000 tons of scrap, mainly in the heavy grades, have been exported. Furthermore, there is evidence that, in general, home scrap is arising less freely, particularly in the better qualities. Whilst light scrap is not looked upon with favour by the steel industry except in times of dire need, heavy scrap is quite a different matter, and the export of so much good quality raw material is a matter of some concern. True, with the increasing availability of pig-iron resulting from the blast furnace construction programme, there has been a tendency to increase the hot-metal/scrap ratio in the open hearth furnace, but the steelmaking section of the industry should be sufficiently flexible to take advantage of the surplus good quality scrap.

In 1958 steel production fell by 2 million tons, but steel consumption fell much less. For the past eighteen months industry has been living on its stocks, and during that period some ¾ million tons came out of stock which was not known to be there—in other words, the stock figures were unreliable—and it is believed that the hidden stocks are not yet exhausted. However, there are signs that stocks are going to be built up again, which will help to increase the demand for steel and, incidentally, for scrap.

The steel industry, too, has been living on its stocks to some extent—in this case of scrap—and with a view to absorbing a major proportion of the surplus scrap and avoiding a complicated scheme for stocking scrap, steelmakers are to maintain their stocks at least at the present level, and the British Iron and Steel Federation is putting in hand arrangements whereby ship-breaking scrap will be stockpiled at an annual rate of 250,000 tons. The industry is therefore in a position to assure the scrap merchants that scrap stocks will not be reduced below the level held at January 24th, and as far as possible scrap purchases by steelmakers will be commensurate with the rate of consumption. Those companies which have reduced their scrap stocks to a low level will endeavour to raise them to a more normal level, but it is possible that in some areas scrap merchants may temporarily be unable to deliver scrap at the rate required, and some fluctuations in the stocks at individual works may be unavoidable.

Coiled Tinplate

The first coils of tinplate ever to be produced in this country have been made at the Velindre Works of The Steel Company of Wales. So far, about 100 tons of strip tinplate in coil form have been despatched to customers.

When the No. 2 electrolytic tinning line was installed at Velindre, it was equipped with twin recoilers situated immediately following the drive bridle. These have now been brought into use and are ready to supply the demand for coils, which is expected to increase as more users of tinplate equip their works with coil handling equipment. At present only a few companies have the necessary facilities to handle coils, but it is understood that others are planning to include such equipment in proposed new plants.

For the tinplate users there are a number of obvious advantages in being able to obtain tinned strip. Not only does it lend itself more readily to continuous processes, giving increased speed of production, but it allows considerable economy. When cutting can ends, for example, the use of continuous strip can save a considerable percentage of the surface area compared with sheet. In addition, strip is easier to handle as it is possible to pick up in one coil the equivalent weight of five or six loaded stillages of cut plate.

From the production point of view also, there are a number of advantages. Better continuity increases the speed of production, which is a benefit whether the tinplate is despatched in coil form or is cut up before despatch on the company's own cutting lines. In addition, the innumerable minor troubles encountered in cutting and classifying sheets at the end of the electrolytic line are avoided.

Adjustments required to change over the line to coil production have been reduced to a straightforward routine, after which the operations proceed at an increased speed. Strip passing through a down and upcut shears is cut and deflected down a conveyor to the recoiler, where a belt wrapper causes it to coil around a collapsing mandrel. The strip is then recoiled at speed until the required size of coil has been built up, when push button control is then sufficient to shear the strip and deflect the leading end into another conveyor, leading to the second recoiler, without actually stopping the line.

The recoilers are equipped with Askania edge control, which causes each mandrel to be moved hydraulically to follow any direction of one edge of the strip. This provides coils with good uniform sides. Coils which at present weigh up to 7 tons, according to the customers needs, are carefully wrapped in corrugated bituminous paper before being despatched from the works

Meeting Diary

20th April

Sheffield Society of Engineers and Metallurgists. Film Night (Ladies Invited). The University Building, St. George's Square, Sheffield. 7.30 p.m.

27th April

Institute of Marine Engineers, West of England Section. Films: "Engineering at Calder Hall," "Criticality" and "Radioisotopes in Industry." Grand Hotel, Bristol, 7.30 p.m. All visitors welcome.

30th April

Institute of Metals, Sheffield Local Section. Chairman's Address. Professor R. W. K. Honeycombe. Engineering Lecture Theatre, The University, St. George's Square, Sheffield, 1. 7.30 p.m.

6th May

Society of Chemical Industry, Corrosion Group. Annual General Meeting and Chairman's Address. 14, Belgrave Square, London, S.W.1. 6.30 p.m.

7th May

Leeds Metallurgical Society. Annual General Meeting, followed at 7.30 p.m. by "Electric Melting Furnaces," by F. S. Leigh. Lecture Room C, Chemistry Wing, The University, Leeds, 2. 7.15 p.m.

7th-9th May

Institute of Metals. Residential Meeting for Younger Members on "Design and Operational Aspects of Melting Furnaces in the Non-Ferrous Metals Industry," Ashorne Hill, Leamington Spa.

12th May

Society of Instrument Technology, Manchester Section. "Temperature Measurement with Resistance Thermometers," by C. K. Massey. Manchester Room, Central Library, Manchester. 6.30 p.m.

Studies on the Dry Corrosion of Nimonic 80A by Peat Ash

By J. A. Waddams,* B.Sc., M.Sc., F.R.I.C. and
J. C. Wright,† Ph.D., B.Sc., A.I.M., A.M.Inst.F.

An account is given of the effects of typical peat ashes on Nimonic 80A at temperatures of 700°–800° C. Previous work on related aspects of the dry corrosion of high-nickel alloys is reviewed. The present study confirms the opinion that the form of accelerated oxidative corrosion considered is preceded by sulphidation, particularly when alkali sulphate chloride mixtures are involved. A critical examination of the process, using metallographic and X-ray diffraction techniques, is reported which indicates that when Nimonic 80A is subjected to these mixtures at elevated temperatures, the sulphidation process leads to the formation of CrS and Ni_3S_2 ahead of the oxidation front.

DURING recent years a considerable amount of work has been carried out on the design and operation of gas turbines utilising pulverised fuels. The problems arising from corrosion, deposition and erosion by ash particles in the open cycle turbine, and of corrosion and deposition in the heat exchanger of the closed cycle turbine, were recognised from the beginning, and investigations are continuing on several aspects of these problems. The work described in this paper covers an initial survey of the dry corrosion effects of peat ash on Nimonic 80A, the material used for the blading of the gas turbine with which the authors were most closely concerned. This turbine, a 750–1,000 kW. open cycle machine fired by pulverized peat, was designed and constructed by Messrs. Ruston & Hornsby, Ltd., of Lincoln.

It is known that certain nickel-chromium and other alloys are susceptible to attack by sulphur compounds at working temperatures common in turbines. Since sulphur and chlorine, combined in various ways, exist in peat ash, there is a possibility that the Nimonic 80A turbine blades of the peat-fired gas turbine may be subjected to attack by sulphur dioxide formed during combustion, or by solid sulphates contained in deposits which form on the blades.

Mordell and Foster-Pegg, working on an experimental exhaust-heated coal-burning turbine, have reported severe corrosion of Nimonic 75 tubes in the heat exchanger.[1] Sulphur in the oxidised condition did not appear to be responsible for the corrosion, but severe local penetration occurred when reduced sulphur compounds came into contact with the tubes. The importance of oxidising or reducing conditions has also been demonstrated by Simons *et al.*[2] They attributed the violent destruction of high temperature alloys by an excess of sodium sulphate to triggering off an autocatalytic reaction involving sodium sulphate. Even with thin films of the salt, accelerated dry corrosion was observed when the atmosphere was alternately oxidising and reducing. The mechanism suggested was that low valency sulphur compounds produced in a reducing environment formed a low melting point metal/metal-sulphide eutectic which could penetrate the alloy readily. The matrix, damaged in this way, seemed to be far more prone to oxidation than the unaffected metal. In dry corrosion crucible tests, rapid attack was observed when the sulphate was contaminated with carbon, but the pure salt was relatively innocuous. Finally, in thermogravimetric studies, Simons and co-workers showed how easily sodium sulphate could be alternately reduced and oxidised.

TABLE I. ANALYSES OF GARDRUM PEAT ASH IGNITED AT 800° C. AND A TYPICAL COMPRESSOR TURBINE BLADE DEPOSIT RESULTING FROM THE USE OF GARDRUM PEAT FUEL.

Constituent	800° C. Gardrum Ash	Blade Deposit
SiO_2	45·1%	14·0%
Fe_2O_3	16·5%	25·9%
Al_2O_3	14·3%	26·0%
MgO	8·7%	0·8%
CaO	6·5%	4·5%
Na_2O	0·7%	1·7%
K_2O	0·3%	3·3%
SO_3	5·8%	22·9%
P_2O_5	2·3%	0·2%
Cl	0·2%	0·6%

The dry corrosion studies of Shirley[3] on steels and high nickel alloys have given direct information on dry corrosion in the peat-fired gas turbine. Preliminary 1,000 hour tests on two steels and Nimonic 80A, at 770° C. with peat, showed severe attack associated with sulphur pick-up. Laboratory tests demonstrated the effects of various salt mixtures in contact with high temperature resistant materials at temperatures comparable with those encountered in the blade zone of the peat-fired gas turbine. It was concluded that the major part of the attack was not caused by gaseous corrosion products, but that it was initiated by alkali sulphates, contaminated with chloride. As little as 1% chloride was sufficient to promote severe attack at temperatures of 700–800° C. The sulphate-chloride attack was found to increase rapidly from 650° C. to 750° C. Inert materials were found to exert a "blanketing" effect against the arrival of fresh supplies of the corrosive salts.

In the present work, the effects of dry corrosion of the turbine blades under similar circumstances to those covered in Shirley's work have been studied. All the more important constituents found in peat ash have been examined as possible corrosive substances.

Materials Used and Experimental Methods

Peat from Gardrum Moss, near Falkirk, was chosen as a basis for these investigations, because a wide knowledge

* Formerly Head of Department of Applied Science, Wolverhampton and Staffordshire College of Technology, now Research Manager at the Culcheth Laboratories of the United Kingdom Atomic Energy Authority.
† Formerly Senior Research Fellow, Wolverhampton and Staffordshire College of Technology, now Senior Lecturer, Department of Metallurgy, College of Technology, Birmingham.

Fig. 1.—Nimonic 80A specimens : left—before treatment; centre—after 24 hours in Na_2SO_4 + 1% NaCl at 800 C. in air ; right—after 48 hours in the same environment.

of its properties had been built up in associated research programmes and its performance in the gas turbine was well documented. Table I gives a typical analysis of the ash formed on igniting Gardrum peat at 800° C., together with the analysis of a typical compressor turbine blade deposit after a run using Gardrum peat as fuel, the blade region being at a temperature of 730° C. Most of the compounds existing in this peat and in turbine deposits associated with it have been identified by X-ray diffraction techniques. The most important include magnesium, calcium, sodium and potassium sulphates, sodium chloride, calcium phosphate, aluminosilicates, quartz or cristobalite, and ferric oxide.

Nature of the Investigation

The experimental work can be divided conveniently into two sections. The first was concerned with crucible tests, in which the dry corrosion effects of various compounds on Nimonic 80A, at temperatures of the same order as those operating in the peat-fired gas turbine, was assessed quantitively. The second part of the investigation was concerned with determining the mechanism of the corrosion which occurred, using X-ray diffraction analysis and metallographic techniques. Basically, the experimental technique followed the general methods used by Shirley. Dry corrosion tests were carried out on Nimonic 80A cylinders 16 mm. in diameter by 16 mm. long, by half immersing them in synthetic mixtures contained in shallow silica capsules. The Nimonic 80A used in the experiments satisfied specification D.T.D. 736, the chemical composition limits being as follows :

Carbon	.. 0·1% max.	Silicon	.. 1·0% max.
Titanium	.. 1·8–2·7%	Manganese	.. 1·0% max.
Chromium	.. 18–21%	Iron	.. 5·0% max.
Aluminium	.. 0·5–1·8%	Cobalt	.. 2·0% max.
Nickel	.. .. Balance		

Batches of specimens were treated for times of 24 hours or 150 hours at a temperature of 800° C. in a muffle furnace. The corrosion per unit surface was then determined from the weight lost for each specimen by subjecting it to cathodic descaling in molten caustic soda at 400° C. Fig. 1 illustrates various stages in the dry corrosion of the specimens.

The first series of tests was carried out using the main constituents of peat ash, singly and in various combinations, as corrosive media. Details of the media used are given in Table II. At test temperatures, some of the media undergo modification. For instance, the phosphates are converted to pyrophosphates and/or metaphosphates, and sodium silicate melts. For this reason, the media used in certain tests were stabilized for a few minutes at 800° C., cooled and repowdered, to eliminate shrinkage and similar difficulties due to changes on heating. In certain tests, pulverized peat was mixed with the medium at this stage and the specimen placed in contact with the mixture. The addition of a small amount of peat to the corrosive media prior to testing was made to simulate conditions occurring at the surface of turbine blades in the engine when unburnt or partially burned peat reaches the turbine. Following this series, further tests were carried out over longer times, (e.g. 150 hours) using peat ash which had been treated with additional sodium sulphate and chloride to simulate the composition of the ash normally passing the cyclone cleaner used on the engine and subsequently arriving at the compressor turbine blades. The ash of a typical Gardrum peat ignited in a muffle at 800° C. contains about 1·5% Na_2SO_4, 0·4% K_2SO_4 and 0·5% NaCl, but the deposit taken from a blade may contain 10% Na_2SO_4, 5% K_2SO_4 and 1·5% NaCl. In the dry corrosion tests, Gardrum peat ash, adjusted to this composition was used. For comparison, similar tests were again made using Na_2SO_4 + 1% NaCl as the medium.

Experimental Results

The results of these tests are summarized in Tables II and III. Although single results are reported in most cases, repeat checks gave reproducible results. The only serious exception was for Na_2SO_4 + 1% NaCl, and it is for this reason that all the results for tests in the medium are listed.

Discussion of Results

From Table II, it is apparent that of the substances

TABLE II.—EXTENT OF DRY CORROSION OF NIMONIC 80A IN VARIOUS MEDIA WHEN EXPOSED FOR 24 HOURS AT 800° C.

Corrosion Medium as at 20° C.	Weight Loss after Descaling (mg./sq. cm.)					
	Medium Only	Medium + 1% NaCl	Medium + 1% Peat	Medium + 1% NaCl + 1% Peat	Medium + 25% SiO_2	Medium + 25% Fe_2O_3
Air	0·280 0·345					
Na_2SO_4	0·523 0·610	1·67 1·70 2·02 76·60 435·0	0·49	421·0	0·50	0·50
K_2SO_4	0·94	34·40	1·11	226·0	0·67	0·58
$CaSO_4$	0·89 0·85	3·34	1·05	5·68	0·50	0·67
$MgSO_4$	0·74	2·17	0·69	4·21	0·50	0·68
NaCl	21·50		47·90		10·50	19·80
$Ca_3(PO_4)_2$	0·40	10·80	0·86	9·1	0·50	0·40
SiO_2	0·60					
Fe_2O_3	0·58				0·50	
Na_2HPO_4	1·17	30·0	9·00	37·40		
Na_2SiO_3	1·57	12·50	2·94			
50% Na_2SO_4 + 50% SiO_2		39·20				

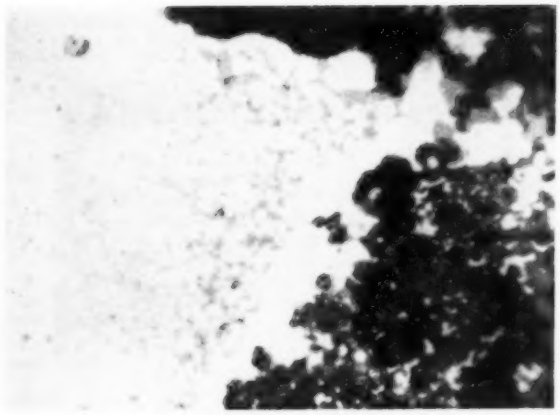

Fig. 2. Metal sulphide and sulphide oxide interfaces in a Nimonic 80A sample after 24 hours in Na_2SO_4 + 1% NaCl at 800° C. in air. Unetched taper section. 200

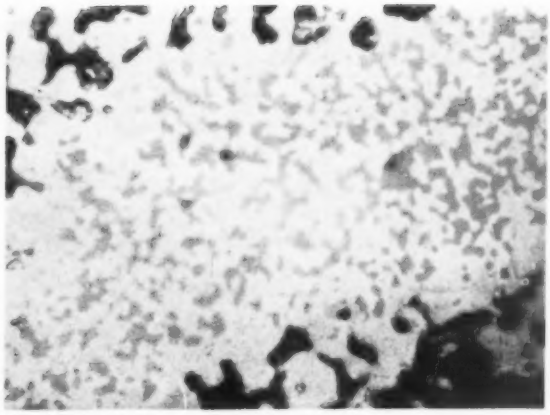

Fig. 3. Details of the sulphide phase ahead of the oxidation front. Unetched taper section. 400

encountered in peat ash, the most corrosive by far are the sulphates of sodium and potassium, particularly when associated with chloride and initially with peat. Calcium sulphate, calcium phosphate, sodium phosphate, sodium chloride and sodium silicate show only moderate tendencies to initiate dry corrosion. Of these substances, sodium silicate was molten during the tests and appeared to flux away the protective chromic oxide, thus giving a fresh surface for further oxidation. This view is supported by the observation that the medium always contained an appreciable quantity of nickel and chromium at the end of the tests using sodium silicate. Fortunately, no completely molten phase has yet been found in the compressor turbine of the peat engine. Indeed, most of the silicates shown to occur in peat ash are quite refractory.

Chloride accelerates dry corrosion in all media, and the presence of peat at the beginning of the test appears to assist the attack, probably because it provides temporary reducing conditions. Relatively inert materials such as silica and ferric oxide appear to play no direct part in the corrosion process, but have a dilution or a shielding effect which results in decreased corrosion. It will be noted that the attack with sodium sulphate sodium chloride mixtures was intermittent, but when the attack did start it was severe. This confirms the findings of other workers (e.g. ref. 2) that the chloride content of the corrosion medium is critical and probably has to exceed a certain threshold value before it effectively accelerates corrosion by sulphates. Although in the present work a chloride level of 1% was used, localised segregation could have caused the chloride threshold level to be exceeded in some tests, but not in others, thus giving variable degrees of attack. The variability of the results could also have arisen from the fact that the test temperature (800° C.) is very close to the melting point of sodium chloride. Slight variations in the crucible or muffle temperature might therefore have caused this constituent to be molten in some tests and not in others.

TABLE III.—EXTENT OF DRY CORROSION OF NIMONIC 80A AFTER 150 HOURS AT 800° C. IN AIR.

Specimen	Weight Loss after Descaling (mg./sq. cm.)	
	Doped Peat Ash + Peat	Na_2SO_4 + 1% NaCl + Peat
Normal Machined N80A	10·0, 14·7, 18·1, 22·5, 25·7	414 398

Table III shows that a combination of sodium chloride, peat and sodium sulphate, over a relatively long time, makes attack virtually certain. It also indicates that, over long periods, dry corrosion of the Nimonic 80A blades in the turbine is to be anticipated at turbine inlet temperatures (725° C.). This is of increased importance when peats other than Gardrum peat are used. Work on parallel parts of the peat turbine research programme has shown that blade deposits resulting from firing with Altnabreac or Lullymore peats have considerably higher sulphate and chloride contents. For instance, a short engine run using Altnabreac peat produced a compressor turbine stator blade deposit containing more than 80% of sulphates and chloride.

X-ray Diffraction and Metallographic Studies

When Nimonic 80A is heated in air to a temperature similar to that encountered in the compressor turbine (725° C.) it becomes coated with a thin, but strongly adherent protective film of α-Cr_2O_3. A similar protective film has also been shown, by X-ray diffraction, to form at a temperature of 800° C.

X-ray diffraction patterns (using copper Kα radiation), of the oxidized surface on solid specimens of Nimonic 80A exposed in a peat fired combustion rig built to simulate conditions in the peat-fired turbine, matched a standard pattern of the hexagonal form of chromic oxide. An example of a comparison of the experimentally determined data with diffraction data, given in the

TABLE IV.—DIFFRACTION DATA FROM A SCALE FORMED ON NIMONIC 80A AFTER SEVERAL HOURS AT 800° C. IN AN ENVIRONMENT OF PEAT ASH BUT FREE FROM SULPHUR ATTACK.

Experimental Spacings		Cr_2O_3 (ASTM 6-0504)	
dA	Intensity	dA	Intensity
5·70	70	5·655	74
3·09	10		
2·66	80	2·666	100
2·47	80	2·480	90
2·17	50	2·176	58
2·07	10	2·048	9
1·81	50	1·8156	59
1·74	10		
1·68	100	1·672	91
1·61	10	1·579	15
1·47	20	1·465	25
1·44	40	1·4314	40
1·309	15	1·2961	20
1·094	15	1·0874	17
1·054	15	1·0422	16

TABLE V.—DIFFRACTION DATA FROM A TAPER SECTION THROUGH A DRY-CORROSION FRONT CAUSED BY SODIUM SULPHATE/CHLORIDE ATTACK ON NIMONIC 80A.

Experimental Spacings		CrS (ASTM 2-1224)		CrS (ASTM 2-1218)	
dA	Intensity	dA	Intensity	dA	Intensity
3·55	10				
2·98	60	3·00	70	2·98	60
2·92	40				
2·66	80	2·67	80	2·64	90
2·52	10				
2·08	100	2·08	100	2·07	100
1·82	30				
1·73	80	1·73	70	1·72	90
1·68	30				
1·62	5	1·62	20	1·61	40
1·48	10			1·49	10
1·44	10	1·45	40	1·45	40
				1·44	40
1·33	10	1·33	40	1·33	90
1·18	10	1·18	20		

The experimentally determined spacings listed above refer to all lines visible on the film after eliminating the heavy pattern of the nickel-chromium solid solution. The lines still unaccounted for are almost certainly due to chromic oxide, but are offset compared with the sulphide.

A.S.T.M. X-ray diffraction data index, is set out in Table IV. In contrast, the attack by sulphate/chloride mixtures produced scales consisting principally of nickel oxide, usually very intimately mixed with the corrosive medium, and not of chromic oxide.

Typical microstructures from taper sections through the scale/metal interface after a Nimonic 80A specimen had undergone 24 hours in Na_2SO_4/NaCl at 800° C., are illustrated in Figs. 2 and 3. Ahead of the advancing oxidation front is a narrow band of a grey phase which is typical of this type of dry corrosion. Areas of this grey material were sufficiently prominent in several taper sections through attacked specimens to be struck accurately with a 0·7 mm. diameter X-ray beam. X-ray diffraction patterns were therefore recorded direct from the taper sectioned microspecimens. Three such areas were examined and in two sections, and probably in a third, chromous sulphide (CrS) was identified. The X-ray diffraction data for one specimen, which showed the lines of CrS superimposed over those for the nickel-chromium solid solution of Nimonic 80A is given in Table V. Table VI gives the diffraction data for another section which showed lines other than those of Nimonic 80A and CrS. From this it will be seen that strong evidence is available for supposing that Ni_3S_2 is also present at the dry corrosion interface, and that both nickel oxide and chromic oxide (hexagonal Fe_2O_3 type structure) also form near to the interface.

Suggested Mechanism of Sulphate/Chloride Attack on Nimonic 80A

At the interface between the nickel-chromium solid solution and sodium or similar sulphates, localised and temporary reducing conditions can arise in the manner already described. This favours the formation of sulphides. Under these conditions it is probable that sodium sulphide forms first, sulphur ions readily diffuse into the matrix at temperatures of the order of 800° C., and chromous sulphide and nickel sulphide are formed, both in a reducing environment. Subsequently, oxidizing conditions, following the advancing sulphide front, are able to cause vigorous oxidation of both nickel and chromium. Because of the disruption of the matrix caused by sulphide formation, the customary protection normally afforded by chromic oxide is virtually non-existent. Thus the localised "pitting" corrosion which is observed in the early stages of this type of attack develops rapidly to catastrophic general corrosion. Any scale formed is very porous and weak.

TABLE VI.—DIFFRACTION DATA FROM A TAPER SECTION THROUGH A DRY-CORROSION FRONT CAUSED BY SODIUM SULPHATE/CHLORIDE ATTACK ON NIMONIC 80A.

Experimental Spacings		Ni_3S_2		CrS		Cr_2O_3	
dA	Intensity	dA	Intensity	dA	Intensity	dA	Intensity
3·63	20	1·09	70			3·633	74
3·20	50						
3·09	50						
2·98	10			3·00	70		
2·87	20	2·87	100				
2·78	20						
2·66	30			2·67	80	2·666	100
2·47	40					2·4801	96
2·37	15	2·37	60				
2·34	5	2·34	30				
2·19	40					2·176	38
2·16	10						
2·02	20	2·03	60	2·08	100*		
1·82	60	1·83	100			1·8156	30
1·80	40	1·81	100				
1·73	10			1·73	70		
1·67	60	1·67	30			1·672	90
1·65	40	1·66	100	1·62	20		
1·46	15					1·465	25
1·42	40			1·45	40	1·4314	40
1·34	10	1·35	30	1·35	90		
1·29	40	1·29	50	1·30	40	1·2961	20
1·22	10	1·22	30				
1·09	20					1·0874	17
0·866	10					0·8658	23

Line of CrS marked * would be masked by NiO line 2·088. In addition, the same film carried heavy lines due to nickel oxide, 2·42 (90), 2·09 (100), 1·48 (50), 1·26 (15), 1·204 (10), 1·045 (10), 0·958 (10), 0·934 (20), and to the nickel-chromium solid solution of Nimonic 80A, 2·04 (100), 1·76 (80), 1·24 (60), 1·066 (70), 1·030 (20), 0·881 (15), 0·810 (40), 0·792 (30). The highest spacing line which could have been measured would have been 3·80. Thus, the line 4·09 of Ni_3S_2 was not observed.

Particles of sulphate appear to be engulfed, and adequate diffusion of fresh corrosive media to the interface is allowed. The attack appears to be catalysed by the presence of chloride. A considerable amount of work has been carried out on the part played by chlorides in this process. Results of considerable interest have been obtained and these will be reported in a later communication.

Conclusions

Dry corrosion of Nimonic 80A turbine blades is possible under conditions operating in the compressor turbine of an open cycle peat-fired gas turbine operating at a temperature of the order of 730° C. This corrosion is mainly due to sulphur absorption followed by heavy oxidation. The most effective corrosive media are sulphates of sodium and potassium, particularly when contaminated with chlorides and peat, or under reducing atmospheric conditions. Other materials present in peat ash, apart from sulphates, can also cause dry corrosion, but they are much less destructive than sodium sulphate.

The accelerated oxidation of Nimonic 80A under these conditions is apparently preceded by the formation of sulphides of nickel and chromium, which are derived from sulphates under localized reducing conditions.

Acknowledgments

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Observations on the Process of Nickel Deposition by Thermal Decomposition of Nickel Carbonyl at Low Pressures

By L. W. Owen, B.Sc.

Atomic Weapons Research Establishment, Aldermaston

An account is given of observations made and experimental determinations carried out during the development of a method for the deposition of nickel by thermal decomposition of nickel carbonyl at low pressures. Details are given of the variables controlling the process and the properties of the coatings obtained, such as appearance, micro-structure, micro-hardness, ductility, etc. The adhesion and porosity of the coatings on various metallic bases are assessed and also such factors as the control of thickness applied and the distribution on various shapes. The role of variables such as temperature, pressure, rate of flow and composition of vapour are discussed and an attempt is made to relate these factors with each other and the properties of the coating.

I. INTRODUCTION

IN recent years interest has grown in a technique of deposition whereby a metal in the form of a volatile compound is caused to decompose at or near to the surface of an object to be plated, so that the metal is deposited in the form of a coating. The most suitable compounds are carbonyls and halides, decomposition being effected by heat alone in the case of metallic carbonyls, or with the aid of hydrogen in the case of metallic halides. Not a great deal of factual data has been published on the technique of vapour deposition, but it is evident that the processes are not by any means so easy to operate successfully as might at first be supposed. Nickel deposition by thermal decomposition of the carbonyl was selected for study, since the method appeared to offer most promise of yielding acceptable coatings (it is reported to have reached a stage of commercial application in the U.S.A.[1]). According to the patent literature, plating can be carried out by this method over a wide range of pressure, but operation at low pressures appeared to have advantages in certain possible applications. Conditions governing satisfactory deposition are referred to in a recent British patent.[2] The properties of nickel carbonyl and decomposition of the vapour have been fairly extensively studied (see Appendix A), but the mechanism of deposition of nickel and the properties of the coatings obtained have received little attention. With the exception of the published methods for plating molybdenum,[3] tungsten[3] and chromium,[4] there was also little guidance available on the type of equipment to be used. It has consequently been thought necessary to record observations, experiences and results of experimental determinations in more detail than might otherwise be usual in a paper such as this, and it is hoped that the information will be both useful as an introduction to more detailed studies and as a guide to the procedure and practice to be adopted for the operation of the process.

The description of the equipment employed has been given only briefly, since a fuller treatment, including design considerations and the details of practical operation of the process has been given elsewhere,[5] but the method of assessment of the coatings has been described in detail for reference in Appendix B.

II. APPARATUS

The apparatus is shown as a working unit in Fig. 1, and schematically in Fig. 2. In design it was suitable for both experimental and practical application. The equipment consisted of four main parts—the plating vessel, the high vacuum system, the plating vapour system, and the diluent gas system. The function of the plating vapour system was to conduct nickel carbonyl vapour at controlled rates of flow into the plating vessel (P_1P_2 in Fig. 2), either with or without diluent gas

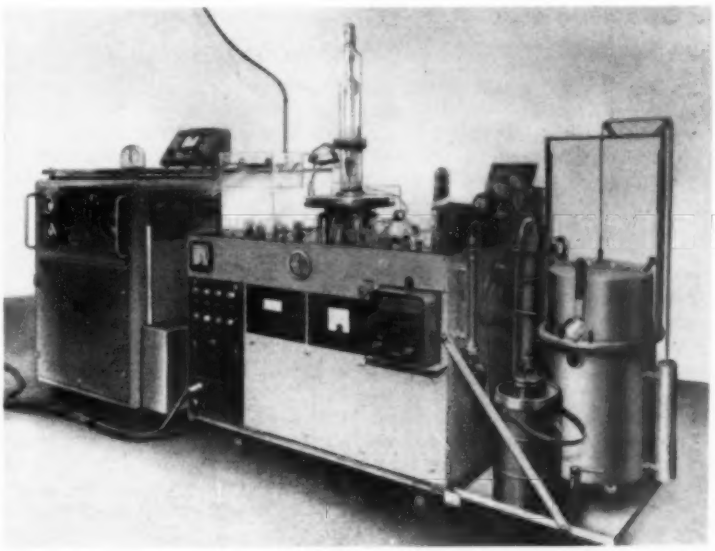


Fig. 1.—General view of the plating unit.

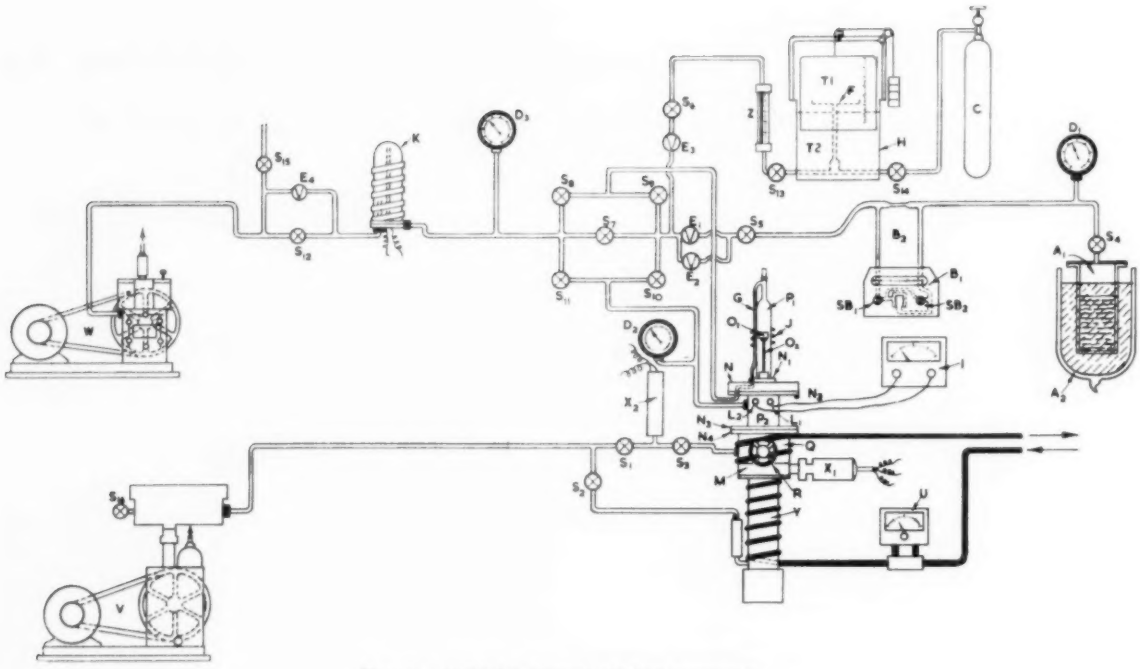


Fig. 2.—Nickel carbonyl plating apparatus.

A_1	NICKEL CARBONYL CONTAINER	K	VAPOUR TRAP	Q	BAFFLE VALVE
A_2	DEWAR FLASK	L_1, L_2	CERAMIC INSULATED ELECTRODES THROUGH WALL OF VACUUM VESSEL P_2	R	BAFFLE VALVE CONTROL
B_1	FLOW INDICATOR—BELLOWS MONOMETER	M	INTERMEDIATE FLANGE BETWEEN THE BAFFLE VALVE Q AND DIFFUSION PUMP Y	S_1–S_{14}	VACUUM VALVES
B_2	FLOW METER CAPILLARY	N	ADAPTOR FLANGE	S_{13}, S_{14}	VACUUM VALVES—AIR ADMITTANCE
C	GAS CYLINDER	N_1	BELL JAR FLANGE	SB_1, SB_2	CONTROL VALVES ON BELLOWS FLOW METER
D_1	DIAL VACUUM GAUGE 0–400 mm.	N_2	FIXED CHAMBER UPPER FLANGE SUPPORTING FLANGE N_3	T_1	GAS STORAGE TANK
D_2	DIAL VACUUM GAUGE 0–10 mm.	N_3	FIXED CHAMBER LOWER FLANGE	T_2	FLUID HOLDING TANK
D_3	DIAL VACUUM GAUGE 0–100 mm.	N_4	BAFFLE VALVE FLANGE	U	WATER FLOW INDICATOR
E_1–E_4	NEEDLE VALVES	O_1	METAL SPECIMEN	V	ROTARY OIL VACUUM PUMP (BACKING LINE)
F	GAS PURIFYING REAGENT TRAY	O_2	STAND FOR SPECIMEN	W	ROTARY OIL VACUUM PUMP (VAPOUR LINE)
G	EXTERNAL DELIVERY TUBE OF BELL JAR P_1	P_1	DEMOUNTABLE BELL JAR	X_1	PHILIPS VACUUM GAUGE HEAD
H	GAS HOLDER	P_2	FIXED CHAMBER BETWEEN BELL JAR P_1 AND BAFFLE VALVE Q	X_2	PIRANI VACUUM GAUGE HEAD
I	TEMPERATURE INDICATOR (MILLIVOLTMETER)			Y	OIL DIFFUSION PUMP SHOWING WATER COOLING COILS
J	R.F. WORK COIL			Z	ROTAMETER TYPE OF FLOW METER

(supplied via the diluent gas system), and thereafter to remove the decomposition products and residual carbonyl vapour at a suitable rate to maintain the desired pressure within the vessel. The high vacuum system incorporated conventional means to produce high vacuum in the plating vessel, and was designed so as to be isolated during plating operations.

The plating vessel served as a suitable enclosure for the specimen (O_1) during the operations of vacuum outgassing and plating. The Pyrex glass bell jar (P_1), a component part of the plating vessel, was demountable so that specimens could be readily introduced and removed. Specimens were heated in the bell jar during outgassing and plating operations by means of a work coil (J) connected to a high frequency induction heating generator (see Fig. 1). The specimens were supported centrally on a stand (O_2) which incorporated thermocouple elements for temperature measurement. The thermocouple leads were conducted through the vacuum wall to the millivoltmeter (I) by means of the vacuum-tight ceramic insulated electrodes (L_1L_2).

High vacuum was produced by means of an oil diffusion pump (Y) backed by the rotary oil pump (V). A Philips cold cathode ionisation gauge (X_1) indicated approximately the degree of high vacuum obtained, whilst backing pressures were recorded on a Pirani gauge (X_2) after appropriate adjustment of the vacuum valves (S_1, S_2). The baffle valve (R) and valve (S_3) were closed during plating, to isolate the high vacuum system from the vapour system.

The nickel carbonyl container (A_1), referred to in a recent British patent,[6] was constructed of Perspex and held up to one pint of liquid. The container was immersed in melting ice in the Dewar flask (A_2) to obtain a source of vapour at constant pressure (indicated by the gauge (D_1)). Condensation of the vapour in the equipment was thus avoided, since the vapour pressure of the carbonyl at ice temperature was substantially lower, i.e., 130 mm., or between half and one-third of that at room temperature. The flow rate of vapour was controlled by needle valves (E_1 and E_2), and measured in terms of the pressure difference across the ends of a capillary tube in the line. A bellows-actuated differential pressure optical manometer (B_1) was employed for this purpose.

Diluent gas, when required, was fed into the vapour

Temperature (° C.)	Efficiency (%)	
80	1	
100	4	
110	9	
120	18	
130	23	
140	35	
160	58	
180	71	
200	86	
220	85	
240	82	
270	70	
300	58	Water Cooled
350	31	Bell Jar Used

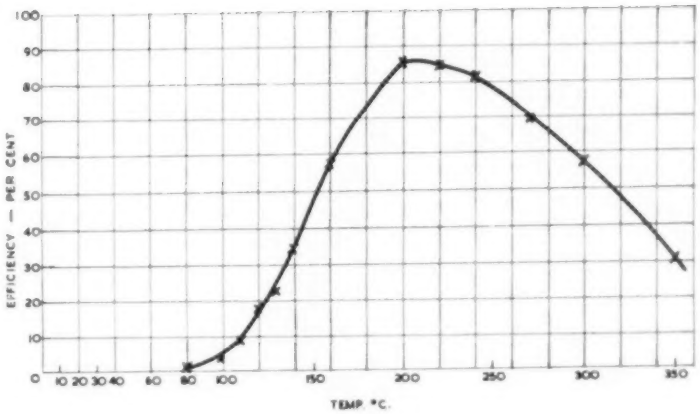


Fig. 3.—Temperature versus efficiency.

line beyond E_1 from a gas holder (T_1) designed to operate at a slight but constant over-pressure. Reagents for purifying the diluent gas were placed on the tray (F) provided in the holder (T_2); the rate of flow was controlled by means of the needle valve (E_3) and recorded on a rotameter (Z). Vapour, with or without diluent gas, was delivered to the plating vessel, or alternatively allowed to flow through the by-pass valve (S_7). A system of valves (S_8–S_{11}) was incorporated in the vapour line to provide a convenient means for reversing the vapour flow within the plating vessel. One of the two vapour lines communicating with the plating vessel was connected as shown to the fixed chamber (P_2); the other line was connected to the fixed flange (N_2). Communication with the bell jar was achieved via a demountable adaptor flange (N), the bell jar flange (N_1), and bell jar delivery tube (G). To provide this continuous passage for the vapour, special vapour channels were cut circumferentially in all three flanges between the concentric "O" grin sealing grooves. The slight disadvantage of the somewhat devious system of communication was fully justified by the advantage of being able to accommodate bell jars in a wide range of diameters on the equipment by merely changing the adaptor flange. Approximate pressures in the bell jar during plating were recorded by dial vacuum gauges (D_2: 0–10 mm., D_3: 0–100 mm.) which were of the sealed capsule type.

Residual gases and vapours were pumped from the bell jar by the chemists type rotary oil vacuum pump (W). This pump, which was fitted with means for adjusting the flow of oil to the rotary vanes of the pump, served to maintain full pumping efficiency in the event of nickel carbonyl passing the hot trap (K). The hot trap was of glass and metal construction, and it was heated by electrothermal tape to decompose residual nickel carbonyl vapour withdrawn from the plating vessel. When high plating pressures were desired at low vapour flow rates, the valve (S_{12}) was closed and the pumping speed reduced to the required amount by appropriate adjustment of the needle valve (E_4).

III. CONDITIONS EMPLOYED

The specimens used for plating tests were mostly flat-ended cylinders, 0·5 in. in length and mostly 1 in. in diameter; a few larger cylinders 3 in. in diameter by 0·5 in. in length were employed in experimental plating for porosity testing. The specimens were supported on the thermocouple stand with the flat ends held horizontally. For small specimens the thermocouple elements (Chromel, Constantan or Alumel) were tapered to a fine point. The cylindrical glass bell jars employed were 2·5 in. in diameter and 12 in. in height, and 7 in. in diameter and about 16 in. in height. The specimens were supported centrally in the bell jar at somewhat less than half its height.

Specimens were vapour degreased in benzene, lightly etched in a suitable pickling solution, rinsed in distilled water, then absolute alcohol, dried and transferred to the equipment, and heated to 400° C. for one hour at 0·1 μ to remove gases adsorbed at the surface. Some metals were given additional pretreatments to promote adhesion of the coating, e.g., brass and aluminium, and details of these treatments are given in Section IV.4. When it was desired to deposit a nickel film to be subsequently stripped for examination—particularly for ductility testing—stainless steel or chromium plated specimens were used and the outgassing treatment omitted.

Unless otherwise stated, observations relate to plating experiments carried out with the smaller specimens and bell jar at the following conditions of plating:—

Temperature: 200° C.
Pressure (in the plating vessel): 1 to 2 mm.
Rate of flow of carbonyl vapour equivalent to 1·0—1·5 g. of nickel per hour.
Direction of vapour flow: downward.

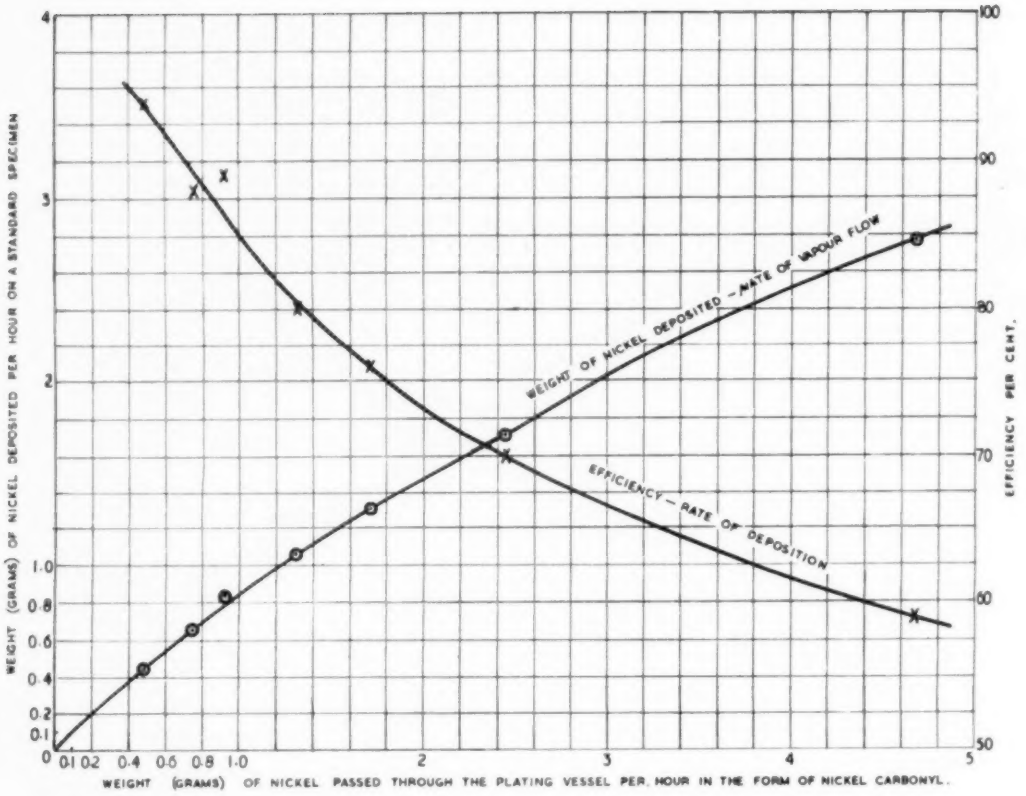
With specimens 3 in. in diameter, the bell jar of 7 in. diameter was employed. The plating conditions were normally the same except that the rate of flow of carbonyl vapour was increased to the equivalent of about 3 g. of nickel per hour.

IV. OBSERVATIONS AND RESULTS

IV.1. Main Variables Influencing the Deposition Process

IV.1.1. Temperature of Specimen

Nickel was deposited as a coherent coating on a specimen whose temperature was as low as 100° C. Efficiency of deposition at this temperature was very low, but at 150° C. it had risen to about 50%. Efficiency of deposition is expressed as the ratio of the weight of nickel deposited to the weight of nickel passed over the specimen in the form of nickel carbonyl (Fig. 3). With a specimen temperature of 150° C. the coating was nearly black in colour, appeared granular or powdery in texture, and was rather brittle. At plating temperatures between 180° and 200° C., the colour of the coating was grey to light grey, becoming progressively lighter in shade with


WEIGHT (GRAMS) OF NICKEL DEPOSITED PER HOUR ON A STANDARD SPECIMEN
EFFICIENCY PER CENT.
WEIGHT OF NICKEL DEPOSITED — RATE OF VAPOUR FLOW
EFFICIENCY — RATE OF DEPOSITION
WEIGHT (GRAMS) OF NICKEL PASSED THROUGH THE PLATING VESSEL PER HOUR IN THE FORM OF NICKEL CARBONYL.

Weight of Nickel Passed (g.)	Weight Deposited (g.)	Efficiency (%)
0·48	0·45	94
0·75	0·66	88
0·93	0·83	89
1·31	1·05	80
1·72	1·30	76
2·44	1·72	70
4·68	2·77	59

Fig. 4.—Rate of vapour flow versus rate of deposition and efficiency at 200° C., and a total pressure of 1·2 mm. Hg.

increase in temperature. At 200° C. the deposition efficiency rose to 85%, and a considerable improvement in texture and ductility of the coating was observed. At 250° C., matt coatings were white in colour, and black powdery deposits resembling soot were usually prominent on the walls of the bell jar near the specimen. This powder was identified as being mainly nickel (or its oxide resulting from exposure to the atmosphere) and it was pyrophoric. The amount of black powder formed increased only slowly at this temperature (250° C.). On increasing the temperature progressively, however, the rate of formation of the black powder increased more rapidly, and in a short time sufficient had accumulated to obscure the specimen from view. Higher pressures and rates of flow of vapour favoured the release of black powder in the form of flakes which could be seen swirling around in the bell jar. This occurred particularly when the vapour was admitted in bursts, and when the plating was carried out in larger bell jars. Under these conditions black threads sometimes appeared, attached to the walls of the bell jar and stand. Ultimately a temperature was reached where plating had to be stopped because there was a risk of the bell jar cracking as a result of the heating in the R.F. field of a bright silvery film of nickel on the inside of the bell jar. On one or two occasions when using the large bell jar, the specimen appeared to be surrounded by a grey cloud which was almost motionless despite the continuous flow of gas. Whisker-like growths, up to ½ in. in length, and tree-like growths have occasionally appeared on the plating specimens under conditions where black powder formation was severe.

Above 200° C. there was little or no increase in deposition efficiency, and at 220° to 230° C., efficiency began to decrease quite rapidly (see Fig. 3). Using the large bell jar and specimens described in Section III, black powder formation was observed to take place at temperatures as low as 200° C. At deposition temperatures of below 200° C., the coatings obtained were frequently observed to have a loose dendritic fissured type of microstructure (see Section IV.6.2.). Long dendrites and fissures were often numerous and pronounced at 150° C., but were less so at higher deposition temperatures, and at 200° C. were only occasionally discernible.

Carbon was found in all coatings tested. The amount at 200° C. was of the order of 0·05%, but rose with increasing temperature to 0·3% at 270° C.

IV.1.2. Rate of Flow of Nickel Carbonyl Vapour

The rate of flow of nickel carbonyl vapour or mass velocity, expressed as grams of nickel (equivalent) per hour, was the main factor determining the rate of deposition. The weight of nickel deposited, however, did not vary in strict proportion to the flow rate, because of the variation in efficiency of deposition with flow rate. The efficiency of deposition varied with the flow rate according to the curve shown in Fig. 4; at the higher flow rates the curve approached a straight line. At very low rates of flow (<0·5 g. of nickel per hour) deposition efficiency approached 100%. At high rates of flow (>5 g. of nickel per hour) deposition efficiency approached 50% and was accompanied by black powder formation.

At high rates of flow coatings were less satisfactory in appearance, but on the whole the quality, although inferior, was not unacceptable. Within the range of flow rates of 0·5–1·5 g. of nickel per hour, coating quality appeared to be maintained, but there was an increased tendency towards black powder formation at the higher flow rate.

Reversing the direction of flow from downward to upward frequently appeared to cause changes in appearance of the coating, the texture becoming coarser with a tendency towards the development of a fissured type of structure (Section IV.6.2.). In experiments employing the larger size of specimen and the large bell jar, the tendency towards black powder formation was also less with upward flow than with downward flow.

IV.1.3. Pressure (in the Bell Jar) and Linear Velocity of Vapour

On increasing the pressure above about 2·5 mm. the coating usually became darker in colour. This effect was usually more apparent when the pressure was increased to 5 mm. and above. At 50 mm. pressure coatings were also generally rougher in appearance and had a fissured dendritic appearance under the microscope. The increase in pressure was effected by reducing the pumping speed, and consequently the linear velocity of the vapour was reduced. At fairly high rates of flow of vapour the effect of increasing the pressure (or reducing the linear velocity of vapour) was to reduce the tendency towards black powder formation, i.e., at a flow rate equivalent to 5 g. of nickel per hour and a pressure of 0·5 mm., black powder formation occurred at a temperature as low as 200° C.; increasing the pressure to 50 mm. resulted in no marked black powder formation until the temperature had been raised by more than 50° C.

IV.1.4. Composition of Plating Gas

Plating experiments were carried out using nickel carbonyl vapour diluted with one or other of the following common gases—carbon monoxide, hydrogen, argon, nitrogen and oxygen. With the exception of oxygen, nickel carbonyl dilution was to the extent of about five volumes.

The deposition efficiency was lowered by diluting the vapour with all gases except oxygen, and an increased tendency for blackening to occur was observed except with carbon monoxide, which had the opposite effect. The only visible effect was produced by oxygen introduced into the bell jar as air.

Fig. 5.—Exfoliation occurring during plating

Small amounts of oxygen of the order of a bad leak, say 2 cm³ of air per hour did not appear to have any effects on the properties of the plate, although if air were introduced into the system near the bell jar, amounts of the order of 10 cm³ per hour appeared to cause roughening of the deposit. Hardness began to increase drastically and ductility to fall at fairly well-defined flow rates of air, the amount depending upon opportunities for mixing. With good mixing the amount of air required was between 100 and 200 cm³ per hour, but with air introduced near the bell jar the same effect was observed with less than half these amounts. At this stage grain structure was very fine or invisible at moderate magnifications. By further increasing the proportion of air, extreme hardness and brittleness resulted and a brightening effect was obtained. The brightening effect was such that the normal initial brightening of the deposit could be maintained almost indefinitely. Further amounts resulted in a banded type of structure and, ultimately, visible oxidation of the deposit, evident from the appearance of characteristic interference colours which disappeared as soon as the proportion of oxygen or air was reduced again. Embrittlement of the deposit was frequently accompanied by stress which caused exfoliation during plating (Fig. 5). It was also noticed that the colour and texture of the coating did not change so readily when the pressure or temperature was varied. It was occasionally observed that at large flow rates of air, the atmosphere surrounding the specimen became foggy, the boundaries being clearly defined and giving the appearance of a stationary cloud or halo. This effect was not unlike that observed under certain conditions when plating at high temperatures, and is noteworthy in that the cloud remained stationary within a moving stream of vapour; a slight reduction in flow rate was usually sufficient to cause it to disperse instantly.

Hydrogen had the opposite effect to oxygen, in that coatings obtained were considerably darker in colour than usual. In common with other gases used, hydrogen

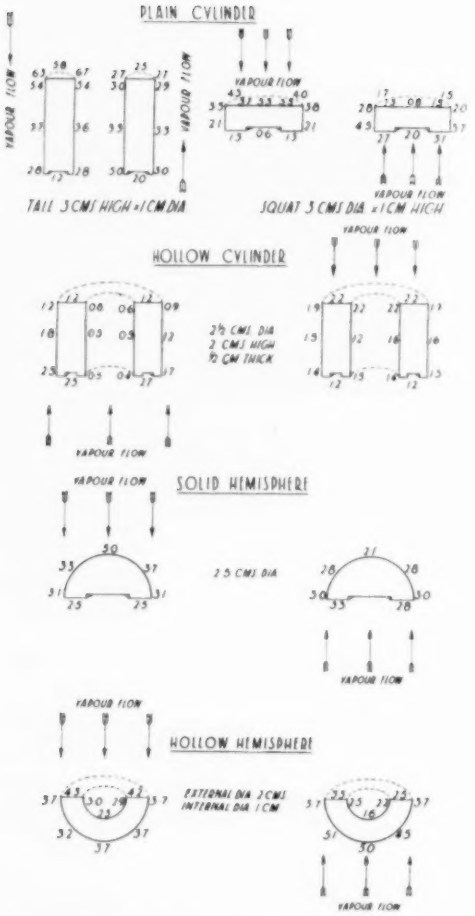


Fig. 6.—Distribution of coating thickness (in. × 10^{-3}) on simple shapes.

also had the effect of increasing the tendency towards black powder formation in the bell jar during plating. This tendency was more marked, however, than with the other gases, probably on account of the high thermal conductivity of this gas relative to other gases.

Carbon monoxide had no readily observable effect, but it became apparent that its use was beneficial in practice under conditions where an undesirable degree of blackening was taking place, as for example when plating large specimens (see Section IV.1.5.).

The tendency for fissure development in the coating at 200° C. appeared to be prevented by the use of carbon monoxide, but only at pressures below 10 mm.

IV.1.5. Size of Specimen and Bell Jar

During the course of the work it was observed that black powder formed much more readily when large specimens were being plated in the 7 in. diameter bell jar than with small specimens in the 2·5 in. diameter bell jar. The rate of plating in terms of thickness per hour could not be maintained without excessive black powder formation at a specimen temperature of 200° C. With similar conditions in the small bell jar, a specimen temperature of 250° to 300° C. could be employed without excessive blackening. By reducing vapour flow by two thirds, plating was possible at 220° C. without excessive blackening, and the introduction of 5 l. per hour of carbon monoxide almost completely eliminated it.

IV.2. Distribution of Coating Thickness Over Simple Shapes

Thickness figures illustrating typically the distribution obtained by coating specimens of certain simple shapes are given in Fig. 6. In some instances the distributions obtained with both downward and upward vapour flow are shown. The coating normally increased in thickness in a direction opposite to the flow of plating vapour, and hence a more uniform distribution was obtained by employing successively both downward and upward flow. A much higher " throw " was obtained into the bore of the hollow cylinder (Fig. 6) than expected, the thickness

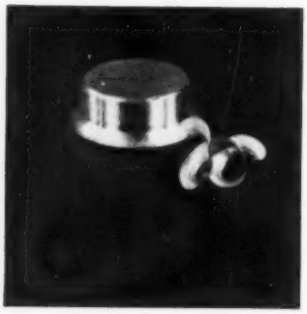


Fig. 7.—Composite swarf test for adhesion of nickel coating to copper base. × 1

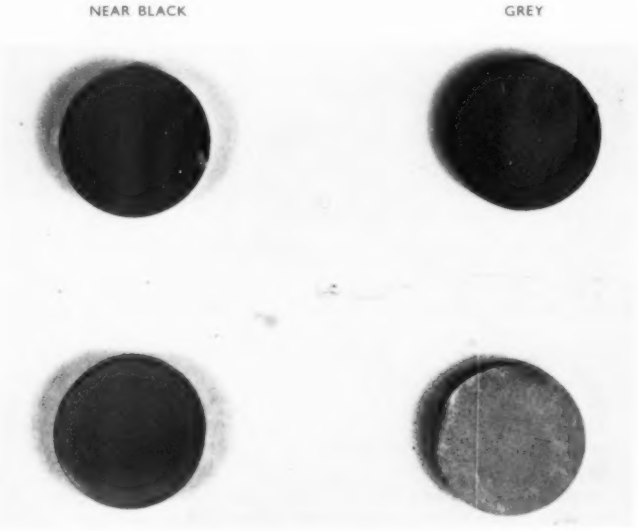


Fig. 8. (right)—Variations in colour of nickel coatings. × 1

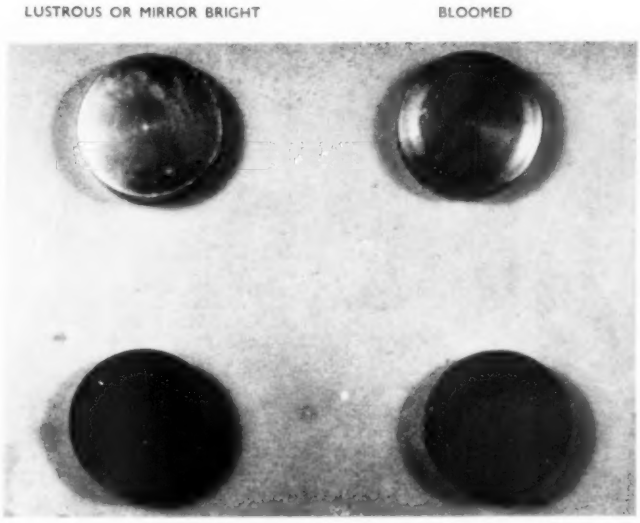


Fig. 9. (left)—Variation in surface texture of nickel coatings. × 1

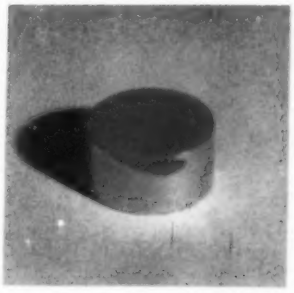


Fig. 10. Partial transformation of coating from bright and lustrous to matt. × 1

of the coating in the bore being approximately equal to that of the outside for downward flow, and a little less than this with upward flow. It is probable that since the cylinder was open at both ends convection currents carried plating vapour freely through the bore. Preferential deposition took place to some extent on prominent areas and on sharp edges, but generally this was of a low order. Good distribution was obtained in " blind bores " by conducting the vapour down a tube terminating close to the " blind " recess. It was observed that at temperatures above about 230° C. there was a noticeable deterioration in " throw " into recesses and a marked tendency for local build up to occur on edges and sharp corners.

IV.3. Ability to Deposit a Desired Average Thickness

The weight of nickel coating applied to a specimen under steady conditions of plating, was determined by the amount of nickel carbonyl passed through the plating vessel and the efficiency of deposition (Fig. 4). Efficiency was predetermined and the amount of nickel carbonyl required to give the desired coating weight calculated. The accuracy to which the desired coating weight was obtained depended largely on the closeness of control exercised during the plating operations. Under optimum conditions the desired weight of coating was achieved within $\pm 5\%$.

IV.4. Adhesion of the Coating to Various Metallic Bases

Coatings were applied to aluminium, brass, copper, lead, magnesium, mild steel and zinc.

The highest degree of adhesion—fairly strong to strong—was obtained on copper. Attempts to separate an isolated portion of the nickel coating from the copper often resulted in chips of nickel being detached with copper adhering to the outside. Visual evidence of good adhesion is illustrated in (Fig. 7), which shows nickel and copper coming away as a composite swarf on taking a heavy cut from a thickly plated copper cylinder. Moderate adhesion was obtained on aluminium but not always consistently. Treatment in a solution of sodium zincate containing " free " sodium hydroxide, following the procedure recommended by Bullough and Gardam[7] for obtaining adherent electrodeposits on aluminium and its alloys, resulted in a lesser degree of adhesion between the nickel coating and the aluminium base.

On brass, weak to moderate adhesion was obtained, especially when the temperature had been raised after outgassing treatment to permit evaporation of some of the zinc. On steel, weak adhesion was obtained, but this was greatly increased by post deposition heat treatment. Coatings obtained on lead and magnesium were rarely more than weakly adherent. Removal of the visible film from lead specimens, by pickling in concentrated hydrochloric acid, resulted in some improvement in adhesion.

IV.5. Porosity of the Coating

Porosity was revealed in the carbonyl nickel coatings by chemical porosity tests when the coatings were below a certain thickness. On aluminium cylinders machined to a fine finish, no pores were found on the test face at a thickness of $0{\cdot}5 \times 10^{-3}$ in.; at slightly less than this thickness, isolated pores were revealed, and at $0{\cdot}25 \times 10^{-3}$ in., numerous pores were detected. Similar results were obtained on steel.

IV.6. Some Physical and Mechanical Properties of the Coating

IV.6.1. Appearance

IV.6.1.1. Unaided Vision

At standard conditions of plating (Section III), coatings appeared silvery in colour and mirror bright at the commencement of plating, but after attaining a certain thickness, usually a few ten thousandths of an inch, they assumed a matt appearance and a light greyish colour. This change usually commenced at a certain area or areas on the film, which gradually increased in size as plating continued, until the whole coating was uniformly transformed. The coating usually retained the same colour for the remainder of the plating period. At other conditions of temperature, pressure, etc., the colour assumed varied from nearly white to almost black

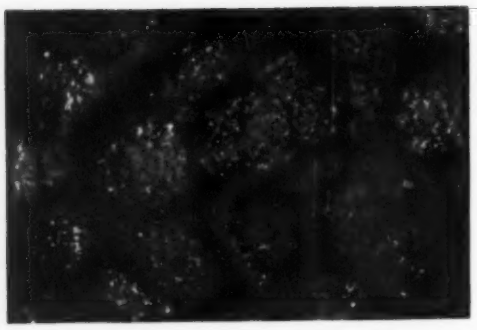


Fig. 11.—Very coarse.

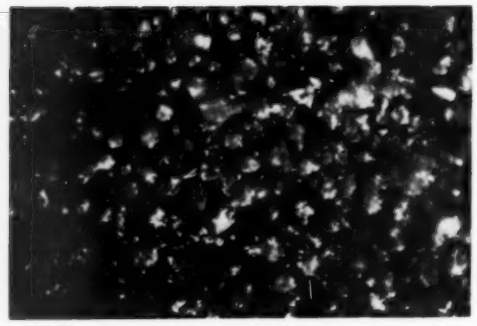


Fig. 12.—Coarse

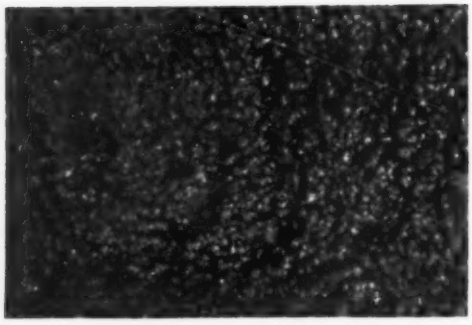


Fig. 13.—Medium.

Figs. 11–15.—Surface texture of coatings under dark ground illumination. × 200

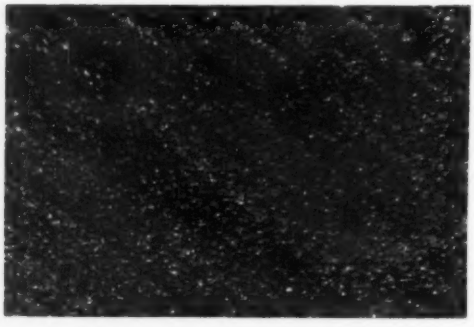


Fig. 14.—Fine.

Fig. 15.—Very fine.

according to the conditions employed (Fig. 8). Exceptionally, coating thicknesses of 2×10^{-3} in. and more were achieved before the appearance of a matt finish, or in contrast matt coatings appeared almost at once, especially where high rates of flow were employed. Mirror brightness was therefore characteristic of almost all deposits formed during the initial stages of plating, and a matt finish characteristic of coatings whose thickness was upwards of 1×10^{-3} in. (except those produced in the presence of oxygen). The degree of mattness found in the coatings varied within the range of a slight haze or bloom through matt to a coarse granular or fibrous quality: Fig. 9 shows examples illustrating the variations. Matt coatings were readily burnished by lightly rubbing with a smooth hard object.

In Fig. 9 a coating which has incompletely transformed on the top right hand side will be seen. Near the periphery the coating is still mirror bright whilst the centre portion shows a bloomed finish (an intermediate stage between mirror brightness and full matt). A more obvious example is reproduced in Fig. 10, where the matt portion is near black in contrast to the silvery bright areas.

Defects such as large nodules, and other types of growth which could be seen with the unaided vision, were only occasionally seen on the thinner coatings (i.e., up to 2×10^{-3} in.). Other defects encountered were craters and plateaux. Craters are flat local depressions in the coating with fairly well defined boundaries resulting from failure of the coating to increase in thickness at the same rate as surrounding areas. plateaux result from deposition in an isolated area at a rate in excess of surrounding areas.

IV.6.1.2. Under Magnification

At low magnification (× 10) small nodules were

usually visible which were not noticeable with unaided vision. At a higher magnification numerous very small nodules, contiguous or isolated, were often seen, which were distributed either in patches or uniformly over the whole surface. At a magnification of the order of 200 diameters most coatings over a certain thickness appeared more or less rough and nodular in structure. The structure varied considerably in degree and five examples have been selected, covering a fairly wide range of roughness seen at a fixed magnification of between 200 to 250 diameters : very coarse, coarse, medium, fine and very fine. Examples of these coatings are given in Figs. 11–15.

(to be continued)

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Science Museum's New Iron and Steel Gallery

A FURTHER stage in the modernisation of the Science Museum at South Kensington, was marked by the recent opening of the new iron and steel gallery by Lord Mills, Minister of Power. There has always been a display dealing with the iron and steel industry, but the existing gallery was inadequate and in many respects out of date. The decision to set up the new exhibition was taken in 1956, the Bessemer centenery year, when the British Iron and Steel Federation and the Science Museum agreed to co-operate in creating a new gallery devoted to iron and steel production. The transformation has involved an expansion from 2,800 sq. ft. to 3,500 sq. ft. of floor space and the expenditure of something like £60,000. More than 250 exhibits are on show, ranging from a slice of mereoric iron to a large bladed alloy steel turbine rotor disc, and these have been drawn from the museums' own collection or contributed by makers and users of steel and iron and steel plant manufacturers.

The display is arranged historically and, starting at one end of the gallery, the first section is devoted to the history of ironmaking and features dioramas of primitive and early ironmaking and exhibits dealing with the manufacture of wrought iron. Opposite to this is a complementary section on the history of steelmaking, with examples of pre-Bessemer steels centred round a Bessemer converter of 1865, which was obtained from the North-West coast, where it fortunately survived the industry's insatiable demand for scrap during the war and immediate post-war years : now it will be presented for posterity.

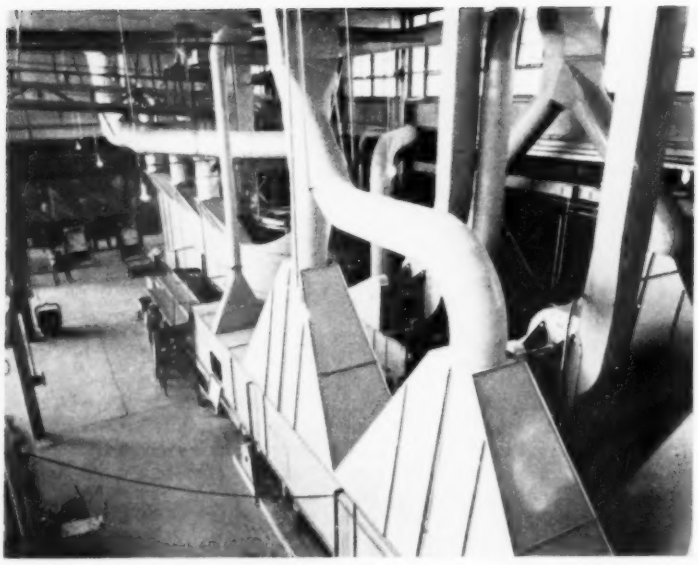
Another major section of the gallery covers modern steelmaking, and includes a full scale representation of part of an open hearth furnace, as seen from the stage, a model of a continuous casting plant, and a push-button induction melting unit which can be operated every thirty seconds to melt the end of a piece of steel wire. Passing on through the sections depicting the most important processes by which steel is worked or shaped, the final part of the gallery—the steel age—is reached. Here, there are exhibits on research and metallurgy, and others to illustrate the importance of iron and steel in the world today.

The central feature of this general view of the new gallery is an early Bessemer converter.

Full size model of part of a steel furnace ; the ladle is half-size.

Cast Outboard Motor Crankshafts

Shell Moulding Technique Adopted



This bird's-eye view of the foundry shows the elaborate ventilating and dust collection system. All air in the foundry is replaced every three minutes.

A NEW foundry, with a 100% shell mould operation, is believed to be among the most highly mechanized shell mould foundries in the United States and the first in the outboard industry ; it is designed to produce steel crankshafts for outboard motors, and has been built for Evinrude Motors at Milwaukee. These shell mould castings are now being used instead of forgings at a considerable saving, because of the reduction in steel required per crankshaft and the elimination of some machining operations. The castings are claimed to be of more closely controlled metallurgical quality than the forgings previously used. The heart of the system is a fully automatic Link-Belt four-station shell moulding machine which can produce a thin shell of resin-bonded sand every 15 seconds, and a shell closing machine which seals cope and drag halves of the moulds together.

The foundry, designed jointly by Evinrude and the Link-Belt Company, also includes a fully integrated sand preparation system ; active storage for 832 moulds ; an overhead trolley pouring conveyor with automatic loading of backing sand and a moving pouring platform synchronized with the pouring conveyor ; automatic discharge into an oscillating conveyor system ; and a recirculating system for backing sand.

Consideration was first given to substituting a cast crankshaft for a forging in late 1952. Experimental patterns were made in 1953, and sample castings were procured from local sources. In 1954, a pilot foundry was set up with minimum melting, shell moulding and related equipment. During the pilot run there was very little mechanization and no automation. The pilot plant proved the feasibility of making the crankshafts from shell moulded castings and indicated the savings that would result. Improvements in the bearing quality of the crankshafts were also noted.

The Link-Belt Company was called in to design the foundry in accordance with the Evinrude requirements, and to furnish the shell moulding and closing machines and conveying and elevating equipment. As a result of the Evinrude pilot operations, the cold coating method was decided upon for coating the sand for the moulds with iron oxide and resin, and a completely integrated sand preparation system was developed.

Sand Preparation

Screened and dried sand from Portage, Wisconsin, of AFS fineness 55–60 is received in covered hopper gondola cars on a siding adjacent to the foundry. The sand is discharged into a track hopper and carried into the building by an 18 in. wide belt conveyor under the foundry floor. A 10 in. by 6 in. centrifugal discharge bucket elevator lifts the sand 53 ft. above the foundry floor and discharges it on to a single-deck, semi-enclosed vibrating screen. The sand from the vibrating screen is delivered to storage by a belt conveyor mounted above a two-compartment storage bin. One compartment of the bin has a capacity of 100 tons, the other of 50 tons. This two-compartment bin is one of several provisions which have been made to handle a two-sand system if it should be needed in the future. The bottom of the each compartment is fitted with a measuring hopper which discharges a predetermined amount of sand into a muller.

Resin and iron oxide are delivered from storage hoppers by screw conveyors to automatic scales. A rotary vane feeder in turn discharges the resin and iron oxide into the muller. An alcohol-water solvent is added to the muller for the cold coating of the sand mix. This operation is completely automatic and can provide 2,000–2,500 lb. of coated sand mix an hour. Sand is discharged from the muller on to a vibrating screen and then conveyed pneumatically to a surge hopper at the shell moulding machine, which consists of sand-resin handling equipment; four pattern frames with built-in individual heating elements carried by a turn-table; a sand-resin investment station; and drives and controls for completely automatic operation.

The shell size is 19½ in. × 29½ in., and the production rate is 120 per hour when operating on a fully automatic cycle. Cope and drag halves are made simultaneously and closed to form a 14¾ in. × 19½ in. mould. At the beginning of a cycle, the heated pattern travels 90° clockwise to the investment station, where it stops and a flask is lowered on to the pattern. The flask, which is water-jacketed to prevent build-up of mix around the outside edges, is invested with a measured amount of resin-coated sand. This material adheres to the pattern, and the sand and resin fuse to form a thin plastic shell.

After a predetermined interval, in which the sand and resin are bonded to desired shell thickness, the connection from the hopper is withdrawn and the pattern and flask are rolled over to discharge excess mix. The pattern, with its adhering layer of sand and resin, then moves clockwise to two successive curing stations, where the shell is baked under electric heaters until the desired hardness is obtained.

At the ejector station the finished shell is automatically stripped from the pattern. The drag half is placed on a flat belt conveyor for setting of cores, if necessary, and then transferred to the Link-Belt automatic shell closing machine, while the cope half is transferred directly from the shell moulding machine to the closing machine. It is set face-to-face upon the drag from the previous cycle of the shell mould machine and the two halves are bonded together. An air-operated mechanism in the four-station shell closing machine holds the two halves together while the adhesive sets. Close tolerances between the cope and drag halves minimize objectionable fins in the finished casting. The shell closing machine is synchronized with the shell moulding machine by means of a variable speed drive.

Mould Storage

When the shell moulds are removed from the closing machine, they are placed on a mould storage conveyor with capacity for 832 moulds. The moulds are stored upside-down in 52 "cars," 16 moulds to a car. When a car is filled with moulds, it is elevated automatically to either of two storage tiers. The car is pushed off the elevator by a pneumatic device, and it rolls by gravity towards the unloading end of the storage rack. The elevator at the loading end then descends to the bottom tier, an empty car rolls on to it, and the elevator lifts the car to the loading position. At the unloading end, another elevator moves up to a pre-selected storage tier, a car rolls on to it, the elevator lowers the car to working level, and the moulds are inspected and transferred to the pouring elevator. After each car is emptied, the elevator lowers it to the return level. The car rolls off and down to the loading end by gravity and the elevator moves up to receive another full car.

The conveyor on which the moulds are poured is an overhead trolley conveyor, 152 ft. long with 57 hinged trays 20 in. wide and 24 in. long on 32 in. centres. Before the moulds are set in the trays, the trays are filled with about 1½ in. of backing sand to support the moulds during pouring. The sand is applied automatically by a Syntron vibratory feeder which is actuated by limit switches which permit only empty trays to receive sand. The overhead trolley conveyor carries the moulds past the pouring platform, which is synchronized with the speed of the mould conveyor.

The poured moulds are carried by the overhead conveyor to either of two pre-selected shake-out stations. Trays are automatically tripped, discharging the castings, mould remnants and sand into a 36 in. wide oscillating conveyor into which backing sand from a second Syntron vibratory feeder has been discharged. The castings, sprues and sand travel over three successive oscillating conveyors, 53 ft., 16 ft., and 60 ft. long, respectively. The three conveyors, each inclined 2°, carry castings, sand and sprues at a rate of 10 ft./min.

The third conveyor has an 8 ft. screening section with ¾-in. diameter openings for screening off the backing sand and finer particles of mould and core sand. This sand is conveyed on a lower trough of the conveyor and then elevated to a belt conveyor discharging to a 20 ton bin for backing sand. The sand is thus continually recirculated.

Castings, sprues and the larger pieces of mould and core sand continue to the end of the oscillating conveyor, where the last 21 ft. serve as a picking table. A divider channels all material to the left side of the trough, and an operator manually throws the castings and sprues over the divider to the right side of the trough. They discharge over the end into a wire basket for further cooling. The refuse sand drops off the end of the conveyor into a tote box.

A high-speed friction cutting band saw is used to cut up sprue and remove the castings from the gating system. The castings are shot blasted and then loaded into alloy trays for a normalize and draw operation. Sprue is also shot blasted and then returned to the charge make-up area. A very extensive system of ventilation and dust control has been installed. Two wet-type and three dry-type dust collectors are used in addition to eleven ventilating fans. The entire foundry air is turned over every three minutes.

The foundry is operated by a staff of twenty men. Four are stationed at the shell moulding and closing machines, one at the storage conveyor for loading the moulds onto the trays of the overhead conveyor, five at melting and pouring, and one at the discharge end of the oscillating conveyor. Additional workers are stationed at the muller, core machine, Wheelabrator, cut-off machines, heat treatment plant and grinders.

Correction

ALUMINIUM IN BUILDING

WE regret that in the article on "The Progress of Aluminium as a Building Material," which appeared in our February issue, the statement was made that in no European country has the percentage used in building yet reached 10% of total output. There is, however, one notable exception, in that this percentage has been exceeded in Switzerland by a very considerable margin, the most recent estimate being 22%.

Welding Machine Replacement

QUASI-ARC have introduced a scheme for replacing automatic welding machines. Self-propelled Fusarc and Fusarc CO_2 machines, extensively used in the shipbuilding and engineering industries, can now be returned within nine years of their purchase, and a fully reconditioned machine will immediately be delivered from stock. The re-conditioned machines will all be of the latest Mark III type and will carry the company's normal 12-month guarantee. The price is fixed regardless of the conditions of the returned machine, provided it is complete, but will depend on age and type.

High Temperature Carburising

By H. N. Ipsen

President, Ipsen Industries, Inc., Rockford, Illinois, U.S.A.

The results of an investigation on the high temperature carburising of a series of U.S. steels, including plain carbon, nickel-molybdenum and nickel-chromium-molybdenum types, indicate that a satisfactory grain structure can be achieved, particularly where a reheat hardening operation is used. Potentenial savings in time and cost are quite substantial, but control of temperature and atmosphere potential become more critical with accelerated carbon penetration.

THE Second World Metallurgical Congress, held recently in Chicago, revealed European success in the application of carburising at temperatures considerably higher than are common in American practice. To those familiar with standard gas-carburising practice, the proportionate increase of carbon penetration with increase in temperature is well-known. However, concensus of opinion indicated that excessive grain growth, and the related effect on physical properties and dimensional stability, limited the temperature of carburising to the range of 1,700–1,750° F. (927–954° C.). Furthermore, the foreshortened life of heat-resisting alloy furnace parts at elevated temperatures mitigates against high temperature carburising from an economic viewpoint.

Steel and Furnace Requirements

Obviously, the furnace manufacturer takes a keen interest in any new heating or heat treating development, and the trend towards processing at elevated temperatures has created active interest in the basic problems involved. The heat resistance of materials of construction, as well as their resistance to the effects of chemical attack, has been given close consideration with regard to furnace usage. Therefore, a successful investigation of high temperature carburising must be dependent upon two factors. First, there must be commercially available standard steels of analysis suitable for carburisation at elevated temperatures, without excessive grain growth. Second, there must be available practical gas carburising furnaces capable of operating at elevated temperatures and under exaggerated conditions of enriched endothermic atmospheres.

Consideration of the first factor reveals that steel suppliers believe many of our present carburising grade steels are, within certain limitations, suitable for treatments at higher-than-normal temperatures. In the light of present available information, general acceptance of gas carburising at abnormally high temperatures is unlikely. Dimensional limits and physical requirements of the part thus carburised may be too critical. However, based on investigation and evaluation of each individual part, it is probable that many will be found adaptable to this new technique. The savings in production cost and time for such parts will certainly warrant the required preliminary investigation.

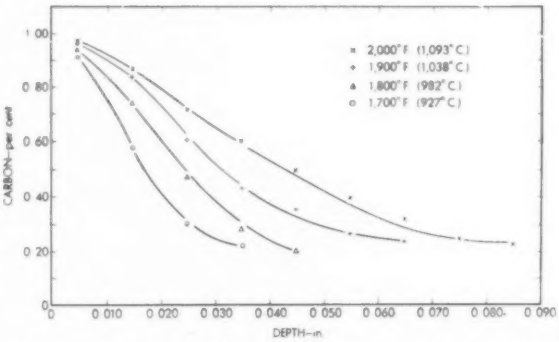


Fig. 1.—Curves showing the carbon content at various depths below the surface of samples of C 1117 steel carburised for two hours at the temperatures indicated.

With a long record of significant developments in high temperature carburising and carbonitriding furnaces, Ipsen Industries, Inc., of Rockford, Illinois, has for some time built small furnaces suitable for gas carburising at temperatures up to 2,000° F. (1,093° C.). The adaptation of the same materials and non-metallic parts to furnaces of larger size and productive capacity was a natural step, and, consequently, the present furnaces of Ipsen manufacture are suitable for gas carburising at elevated temperatures, without major change.

The major contribution to this furnace construction has been the replacement of failure-prone metal alloy furnace parts with similar parts of high density refractory materials. Such parts are currently used in such critical components as hearth and hearth support members, radiant heat transfer tubes, conveyor rollers for both roller-rail and roller-hearth applications, directional flow baffles, and even high speed forced circulation fan equipment. Such parts have been evaluated over the past several years, in actual field operation, under various types of atmospheres and applications, at operating temperatures from 1,400° F. (760° C.) to well in excess of 2,000° F. (1,093° C.). The

TABLE I—PARTICULARS OF STEELS USED FOR CARBURISING TESTS

Steel Designation	Steel Type	Composition (%)							
		C	Mn	P	S	Si	Ni	Cr	Mo
AISI 1117	Carbon	0·20	1·23	0·031	0·113	—	—	—	—
AISI 4615	Nickel-Molybdenum	0·16	0·56	0·034	0·030	0·24	1·77	—	0·22
AISI 8620	Nickel-Chromium-Molybdenum	0·21	0·78	0·028	0·034	0·32	0·64	0·58	0·18
AISI 9315	Nickel-Chromium-Molybdenum	0·16	0·55	0·021	0·018	0·27	3·37	1·25	0·11

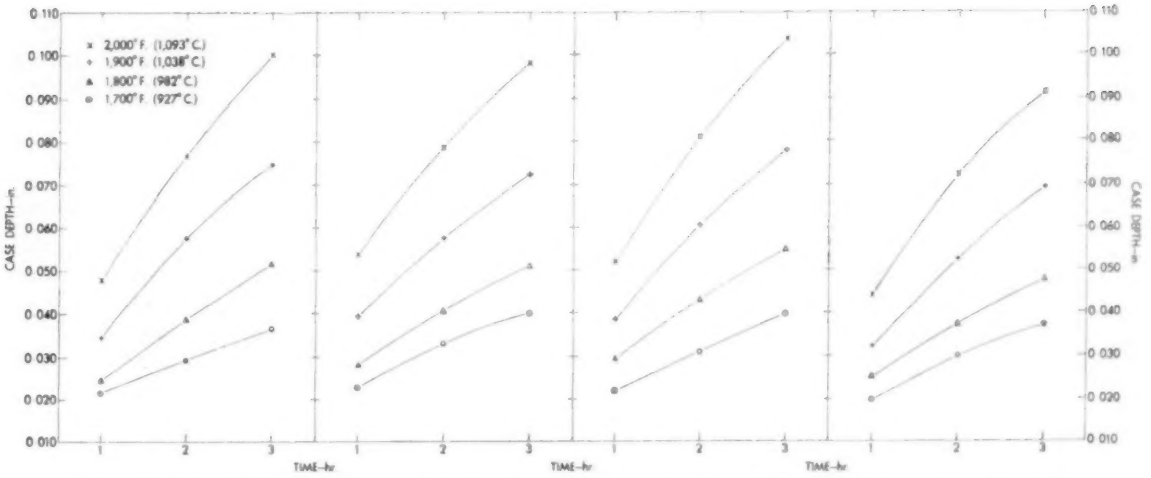


Fig. 2.—AISI 1117 steel. Fig. 3.—AISI 4615 steel. Fig. 4.—AISI 8620 steel. Fig. 5.—AISI 9315 steel.
Figs. 2–5.—Total case depths for the four steels after carburising for 1–3 hours at the temperatures indicated. The key is the same for each set of curves.

incident of a new carburising concept at higher temperatures is, therefore, substantially pre-solved in so far as furnace materials are concerned.

Details of Tests

After considerable study of the available reports from Europe, a preliminary investigation was planned and conducted by Ipsen Industries, Inc., to determine the feasibility of the elevated temperature carburising process, and to investigate the effects of temperature and carbonaceous atmosphere on the furnace involved. Based on existing design, 2,000° F. (1,093° C.) was selected as a maximum furnace temperature for the initial investigation, with parallel tests performed at 1,700, 1,800 and 1,900° F. (927, 982 and 1,038° C.) for comparison. Holding times at each temperature were set at 1, 2 and 3 hours, followed by atmosphere cooling. The possible quench reactions following reheating were studied in subsequent investigations. The tests were conducted with four commercial grades of steel, particulars of which are set out in Table I.

Tests on these steels were carried out in a standard gas-fired Ipsen Model TC-100-G furnace, capable of operation at temperatures up to 2,000° F. (1,093° C.), with enriched endothermic atmospheres used in both heating and cooling chambers. Complete forced convection heating of parts was carried out by means of a newly developed ceramic fan. Standard controlled dewpoint type endothermic generator equipment provided a suitable atmosphere.

Test bars of the four steels investigated were cut into lengths of 3–3½ in., and rough ground to 0·475 in. ± 0·003 in. to remove possible surface decarburisation. The diameter and length of each part was then recorded, and the part stamped for identification. The selected furnace was loaded with the four grades of test bar, interspersed among properly identified new bars of C1018 steel, ⅜–⅞ in. in diameter by 3–6½ in. in length. Twelve such loads were prepared in standard baskets to approximate an individual gross weight of 35 lb.

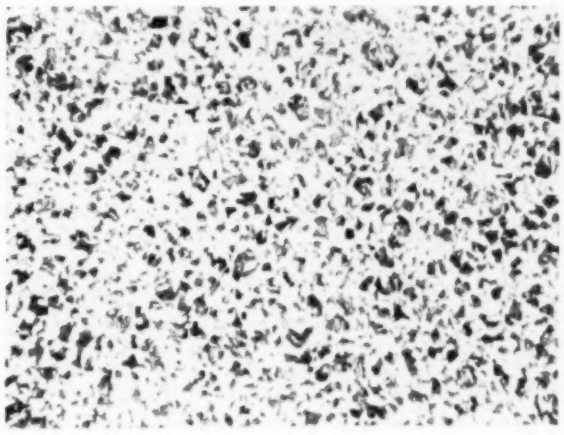


Fig. 6.—Microstructure of AISI 8620 steel prior to high temperature carburising. Etched 2% nital. × 100

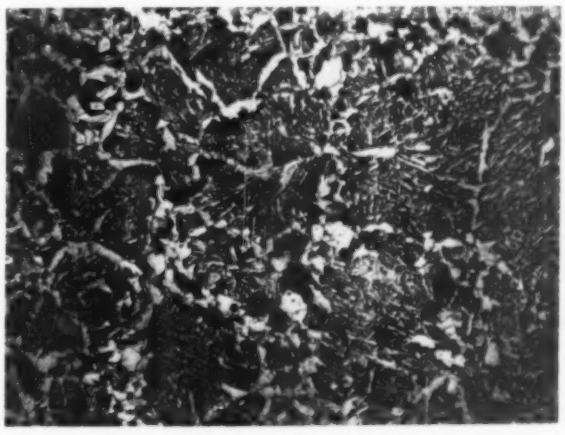


Fig. 7.—Microstructure of the core of a 0·5 in. diameter bar of AISI 8620 steel after carburising for three hours at 2,000 F. (1,093° C.) and atmosphere cooling. Etched 2% nital. × 100

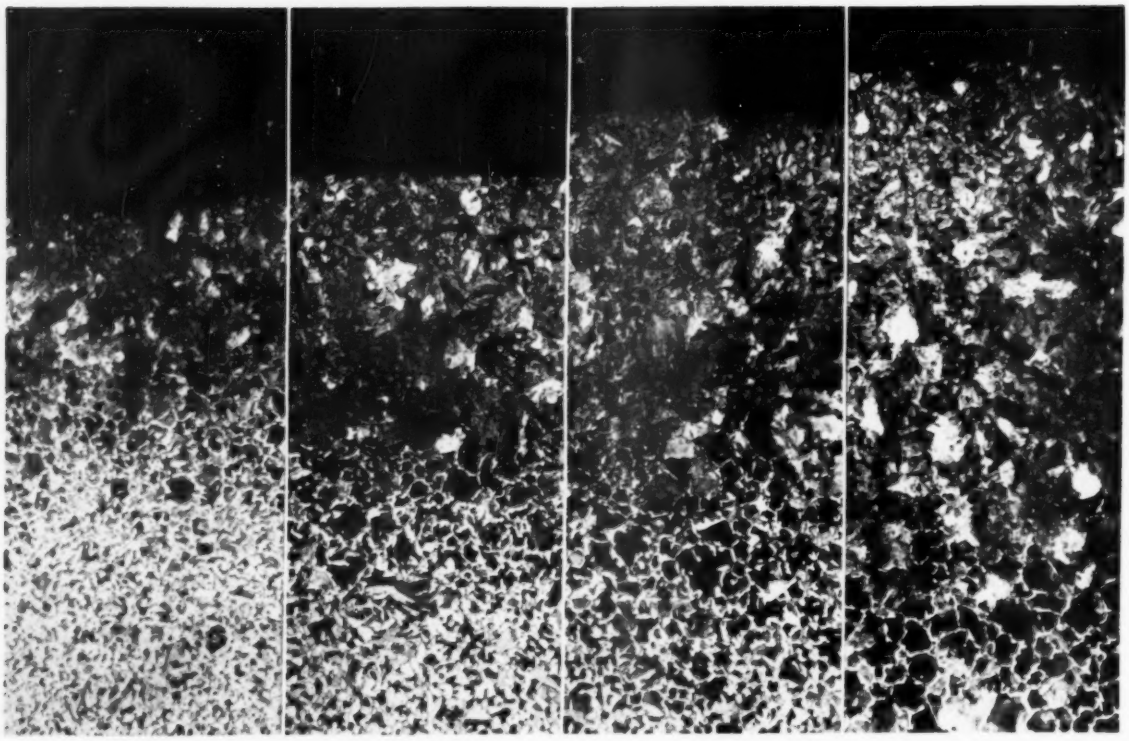


Fig. 8.—1,700° F. (927° C.).

Fig. 9.—1,800° F. (982° C.).

Fig. 10.—1,900° F. (1,038° C.).

Fig. 11.—2,000° F. (1,093° C.).

Figs. 8–11.—Microstructures of AISI 1117 steel after carburising for two hours at the temperatures indicated and atmosphere cooling. Etched 2% nital. × 75

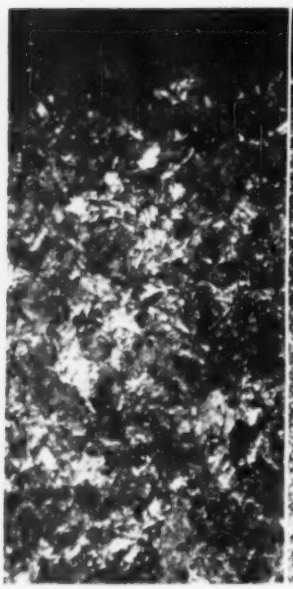


Fig. 12.—AISI 1117 steel.

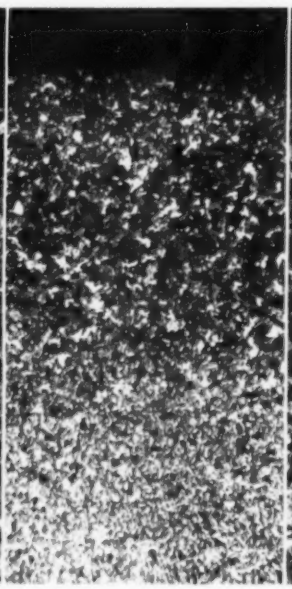


Fig. 13.—AISI 4615 steel.

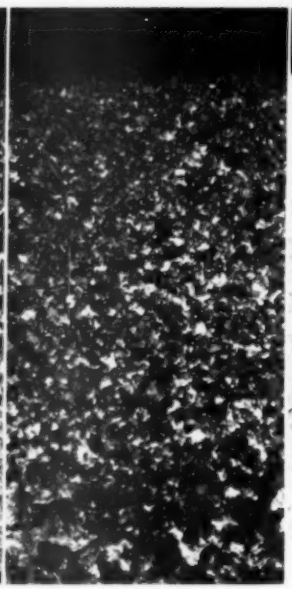


Fig. 14.—AISI 8620 steel.

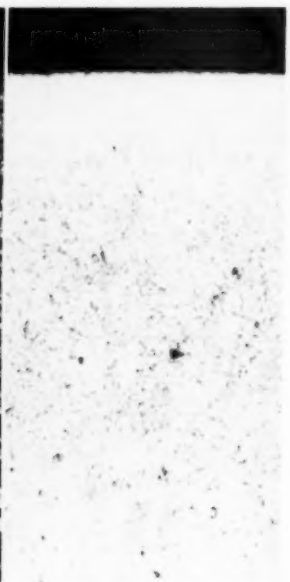


Fig. 15.—AISI 9315 steel.

Figs. 12–15.—Microstructures of the four steels after carburising for three hours at 1,900° F. (1,038° C.) and atmosphere cooling. Etched 2% nital. × 100

Atmosphere from the generator resulted in typical analyses approximating :

CO_2—0°$_0$ H_2—41·2°$_0$
O_2—0°$_0$ CH_4—0·5°$_0$
CO—20·6°$_0$

Automatic air-gas ratio control at the generator provided dewpoints of 35° F. (1·67° C.) for 1,700° F. (927° C.) furnace operation : 25° F. (—3·9° C.) for 1,800° F. (982° C.) ; 20° F. (—6·67° C.) for 1,900° F. (1,038° C.) ; and 15° F. (—9·44° C.) for 2,000° F. (1,093° C.). Additive raw natural gas to achieve the lower dewpoints required for the elevated temperatures of furnace operation was thus held to a minimum, and controlled through an Ipsen Dewtronik. Atmosphere usage amounted to 200 cu. ft. hr., and the raw gas additive varied from 5 to approximately 15 cu. ft./hr. Dewpoints and recovery times were itemised as follows :

	1,700° F. (927° C.)	1,800° F. (928° C.)	1,900° F. (1,038° C.)	2,000° F. (1,093° C.)
Recovery Time ..	10 min.	14 min.	20 min.	31 min.
Dewpoint in Furnace	15 to 17° F. (—9·44 to —8·33° C.)	9 to 11° F. (—12·78 to —10° C.)	7 to 12° F. (—13·89 to —11·11° C.)	5 to 10° F. (—15 to —12·22° C.)
Cooling Time ..	2 hr.	2 hr.	2 hr.	2 hr.

(Dewpoints checked by Dewtronik, Alnor and Visual CO_2 Cup test and interpolated from published curves to conform to a potential of 0·90–1·00°$_0$ carbon at the four temperatures investigated).

After treatment, individual parts were remeasured to check dimensional growth, and microspecimens prepared for the determination of average total case depth, based on different locations on each sample. "Total Case" was considered to be that depth at which case carbon and core carbon coincided. The samples treated for 2 hours were further subjected to successive surface cuts of 0·010 in., the chips were analysed for carbon content, and results plotted in Fig. 1.

Results

The investigation of dimensional growth resulting from higher temperatures indicated relatively no change nor trend relative to type of material or temperature of processing. Other data, including case depth *v* time at temperature is reproduced in Figs. 2 (AISI 1117), 3 (AISI 4165), 4 (AISI 8620), and 5 (AISI 9315).

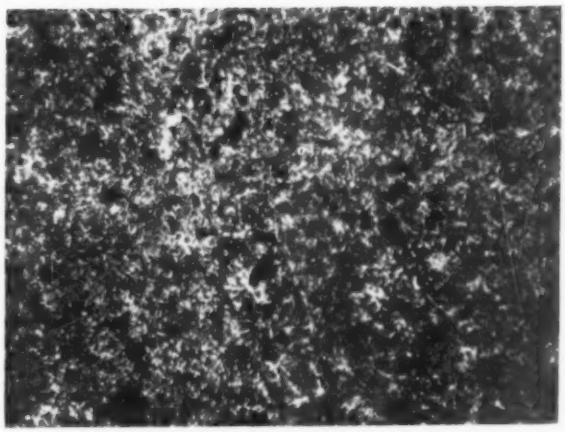


Fig. 16.—Microstructure of the core of a 0·5 in. diameter bar of AISI 8620 steel after carburising for three hours at 2,000° F. (1,093° C.), atmosphere cooling, reheating to 1,500° F. (815° C.) and oil quenching. Etched 2°$_0$ nital. × 100

Grain growth was determined in accordance with ASTM E-19 with the results set out in Table II. Fig. 6 is AISI 8620 steel prior to carburising, and Fig. 7 is AISI 8620 core after carburising for 3 hours at 2,000° F. (1,093° C.) showing the extreme growth of grain from ASTM No. 8 to ASTM No. 3-6 Duplex.

Photomicrographs of the cases of AISI 1117 steel subjected to the four carburising temperatures are shown in Figs. 8, 9, 10, and 11. These are typical of the other cases. Photomicrographs showing the cases of the four steels (AISI 1117, 4615, 8620, and 9315) after

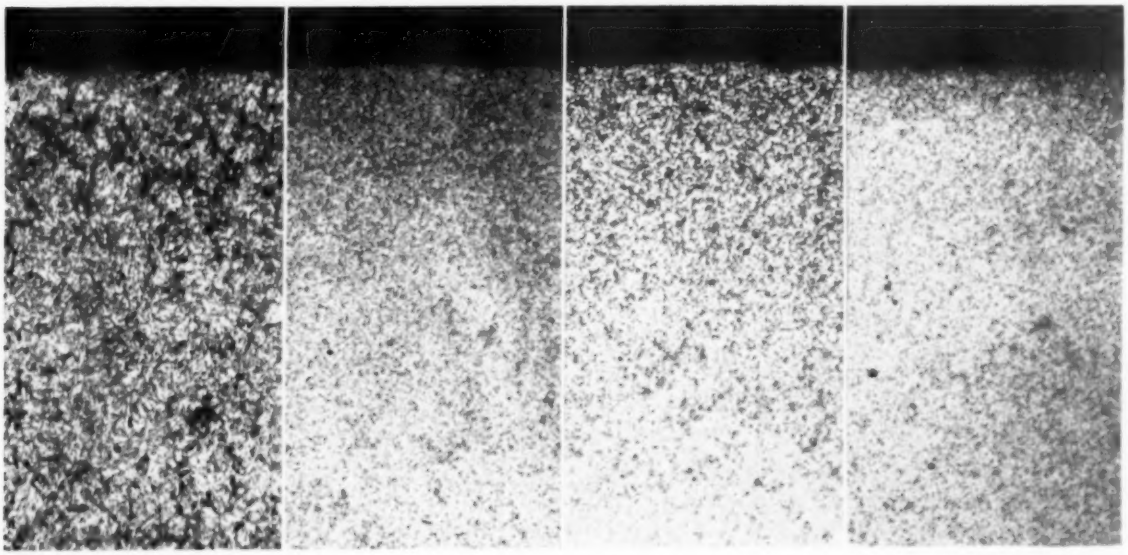


Fig. 17.—AISI 1117 steel. Fig. 18.—AISI 4615 steel. Fig. 19.—AISI 8620 steel. Fig. 20.—AISI 9315 steel.

Figs. 17–20—Microstructures of the four steels after carburising for three hours at 1,900° F. (1,038° C.), atmosphere cooling, reheating to 1,500° F. (815° C.) and oil quenching. Etched 2°$_0$ nital. × 100

TABLE II.—EFFECT OF CARBURISING TEMPERATURE ON GRAIN GROWTH.

Steel Designation	Carburising Time	Grain Size				
		Before Carburising	Carburising Temperature			
			1,700° F. (927° C.)	1,800° F. (982° C.)	1,900° F. 1,038° C.)	2,000° F. (1,093° C.)
AISI 1117	1 hour	8	6–7	6–7	4–6 Duplex	5–5 Duplex
AISI 4615		8	8	8	8	7–8
AISI 8620		8	7	7	4–7 Duplex	4–6 Duplex
AISI 9315		8	8	8	8	8
AISI 1117	3 hours	8	5–7	4–7 Duplex	4–7 Duplex	3–6 Duplex
AISI 4615		8	8	8	8	6–7
AISI 8620		8	7	7	3–7	3–6 Duplex
AISI 9315		8	8	8	8	8

carburising at 1,900 °F. (1,038° C.) for 3 hour cycles are shown in Figs. 12, 13, 14, and 15. These again are typical of other temperatures.

The 1 and 3 hour cycle samples were reheated in an Ipsen T-4-600B-GM furnace and held at 1,500° F. (815° C.) for 1 hour in a controlled furnace atmosphere having 30° F. (—1·11° C.) dewpoint. Samples were then quenched in 150° F. (65° C.) Ipsen Double Duty Oil. The parts were examined microscopically to determine the degree of refinement of the grain size of the cases and cores. Fig. 16, as compared with Fig. 7, shows the results of refinement of the very coarse 8620 that had been carburised at 2,000° F. (1,093° C.). The AISI 1117 showed a similar refinement, but with AISI 9315 and AISI 4615 steels there was no appreciable change.

Conclusions

This preliminary investigation would indicate that upon the steels tested, elevated temperature carburising with retention of satisfactory grain structure is practicable, especially where reheat hardening is employed.

Comparison of cost of operation and initial investment in process equipment for conventional 1,750° F. (954° C.) *v* 2,000° F. (1,093° C.) carburising indicates that more rapid heating and penetration at the higher temperature can substantially reduce the size of furnace equipment required for a given hourly production, all other circumstances being equal.

Control of atmosphere potential becomes more critical at elevated temperatures, and indicates the need for automatic dewpoint control at furnace as well as generator.

Control of temperature uniformity also becomes more critical in the elevated temperature ranges, since accelerated carbon penetration exaggerates discrepancies of temperature differences in the equipment.

Annealing Furnaces for Argentina

DELIVERY began recently of more than half a million pounds' worth of annealing equipment for the new steelworks of Sociedad Mixta Siderurgia Argentina (SOMISA) at San Nicolas, near Rosario, Argentina. All the furnaces for the annealing shop, which is over 350 ft. long and 100 ft. wide, are being supplied by the Incandescent Heat Co., Ltd., as packaged units, completely assembled in England and shipped ready for operation in Argentina. The plant will anneal more than 300,000 tons of steel a year. The complete order will pass through Newport Docks, and will be shipped by the middle of this year.

Part of the first shipment at the dockside.

Forging Press Order

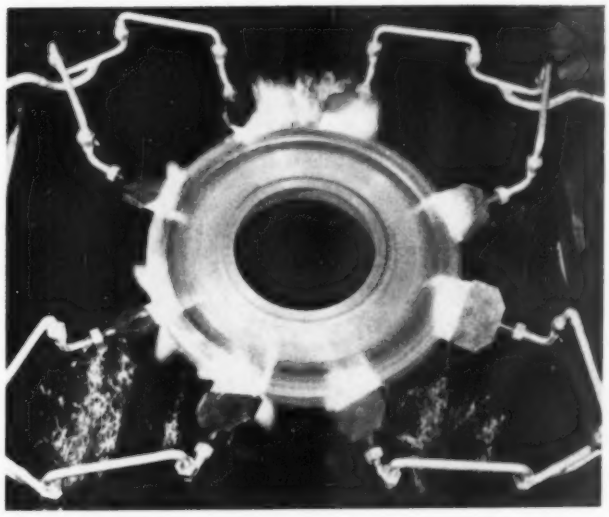
AN order worth over £100,000 has been placed with Davy and United Engineering Co., Ltd., by Brown Bayley Steels, Ltd., for a 1,500 tons hydraulic forging press. The press will be of the single-cylinder four-column type and will be complete with hydraulic tool changing gear. There are two particular points of interest in its design. It will be operated from a direct oil pump drive of the Towler Electraulic type ; this will be the first application in Britain of this type of drive to a forging press of such a size, although it has already been applied successfully to a number of installations abroad. Also the press will be one of the first to be equipped with automatic position control. In addition to other operational advantages, this system enables the movement of the press crosshead to be automatically stopped at any pre-set point on the downwards or upwards stroke, without any necessity for corresponding action on the part of the press operator. The press will be installed in the Leeds Road Works, Sheffield, of Brown Bayley's and is due for delivery in December 1959. It will be built in the Glasgow Works of Davy-United.

Gas Carburising Furnace Order

AN order has been received by Wild Barfield Electric Furnaces, Ltd., of Watford, from the well-known locomotive building firm in Leeds, the Hunslet Engine Co., Ltd., for a large gas carburising furnace 48 in. diameter by 54 in. deep operating on the Carbodrip drip feed system.

Flame-Hardening Excavator Parts

Oxy-Town-Gas Equipment at Ruston-Bucyrus

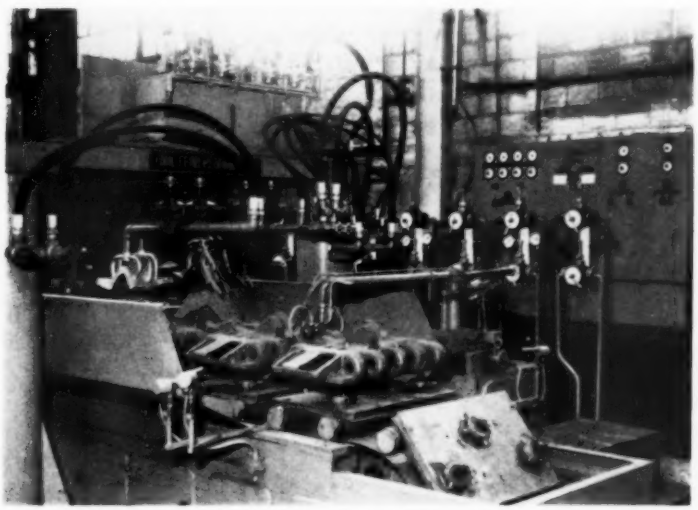


Flame-hardening a gear by the spinning method.

AT the Ruston-Bucyrus Works at Lincoln, production is concentrated mainly on excavators, although some water well drills are also made by the company. In a full year, some 14,000 units can be turned out in sizes ranging from $\frac{3}{8}$ cu. yd. capacity (weighing 10 tons and costing less than £4,000) to 6–7 cu. yd. capacity (weighing over 200 tons and costing more than £80,000). With a payroll in the region of 2,400, the total weight of production amounts to 40,000 tons a year.

Ruston-Bucyrus excavators are exported to every corner of the world, quite apart from their extensive use in this country, and in view of the fact that there are six major makers in this country, about forty in the United States, and some in most countries, competition is very severe. To ensure an adequate share in world markets, the design must be good and the machine must be well-made. To this end the company has spent, during the last ten years, £3$\frac{3}{4}$ million on buildings, plant, machinery, and equipment, and today claims to have the best works of its type in the world.

Many of the important working parts of excavators are subjected to considerable wear by abrasion: dust and mud accounting for much of this trouble. It is, therefore, essential that these components have hard, tough wearing surfaces. It is only these surfaces which needed to be hardened, and the core material is left in its normal condition. To meet this need, the company recently acquired a number of special-purpose oxy-town gas flame-hardening machines, designed and built by the firm of Paul Ferd. Peddinghaus of Gevelsberg, Western Germany. The oxy-town gas flame-hardening method gives easy control and enables a deep case to be obtained: it has been found by experience to be both efficient and economic in operation.

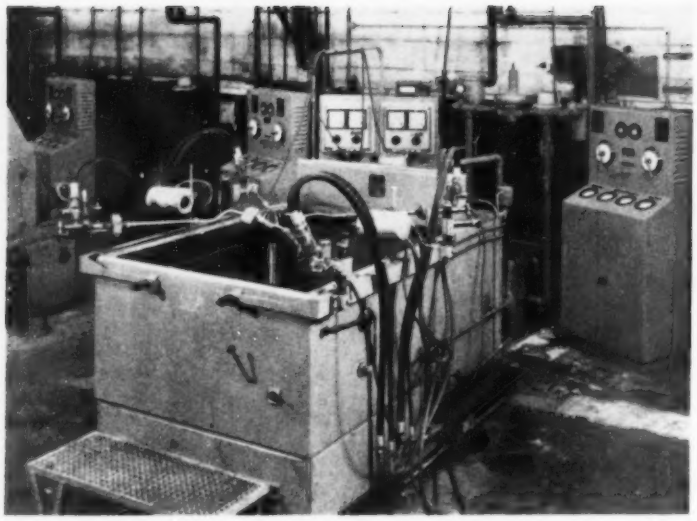


Type BKG machine for flame-hardening the bores, lugs and roller path of excavator track links.

Track Link Hardening

One of the components which has to work under the worst possible conditions is, of course, the track link. The wearing parts are the four holes which bear on the track pin; two heavy lugs which take up the drive from the sprocket; and the roller path which runs on the trailer wheels. To design a machine which would automatically harden each link uniformly and consistently was quite a problem, especially in view of the awkward shape and considerable weight of the component. The Peddinghaus concern undertook the task and the resulting machine is believed to be the largest flame-hardening unit in the world.

The machine comprises a heavy conveyor having eight stations, specially designed burners and quenching equipment, and units for controlling the flame



Machine for flame-hardening gears by the spinning method.

so that reproducible hardening is achieved. At the first, or loading, station, the link is accurately positioned by means of three adjustable supports. The setting of these supports is most important, as it affects all subsequent operations. This is particularly true of the hardening of the bearing holes, when the burner must be accurately centred. The second station is an idle station, in order to allow space for later operations. The third station is that at which the bores of the four bearing holes at each end of the link are simultaneously hardened by means of the progressive method. The four burners are situated two on each side of the machine, and each hardens two bores. The burners and quenches are pneumatically moved inwards to the further end of the bores, and then retracted at the correct speed to give the required depth of hardening, the burner and quench unit being integral.

At the fifth station, which follows another idle station, the lugs are hardened by means of the spot method, in which the whole area to be hardened is heated to the correct temperature and then quenched by sprays. As the track link is moved to the correct position, the conveyor stops and the specially-shaped water-cooled burners, which are pneumatically driven, are moved horizontally to the heating position, where they descend over the lugs and ignite from a pilot flame. On reaching the required temperature they are displaced by spray quenches, which operate for a pre-determined period.

Another idle station is followed by station seven, where the roller path is hardened by the progressive method, the quenches being situated just behind the burners. The link remains stationary, while the burner and quench assembly moves over the length to be hardened at the correct speed to ensure the desired depth. The speed can be varied infinitely by means of a PIV gear box. The eighth and last station is the unloading station.

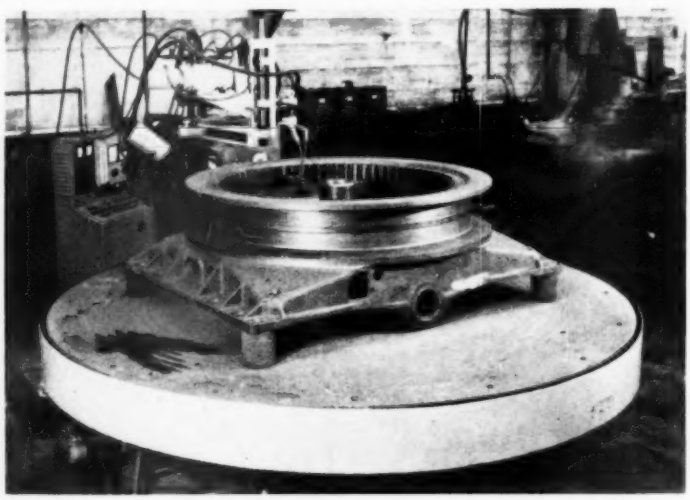
The floor-to-floor time for each link —which may weigh from 4 to 7 cwt. according to type—is approximately 5 minutes. Town gas, enriched with oxygen in the proportion of 60 cu. ft. of oxygen to every 100 cu. ft. of gas, is used for the process, and gas and oxygen supplies for each set of burners are fitted with flow meters and pressure gauges, so that a method sheet can be made out for each type of link to be treated, to ensure satisfactory and consistent hardening. The various operations are controlled by a pre-set programme selector.

Gear Hardening by Spinning Method

Ruston-Bucyrus have also just installed the first machine in the country to flame-harden large gears by the spinning method. The maximum capacity of this model is a gear diameter of 40 in. and a tooth width of 4 in.: larger models are obtainable.

The machine comprises a tank in which the quenching oil is contained, at the centre of which a rotatable spindle is situated, and on this the gear is supported horizontally by means of a suitable adaptor. A number of oxy-town gas burners are arranged around the circumference of the gear. Two Milliscope automatic temperature controllers utilising radiation pyrometers are incorporated, one set tangentially to measure the temperature of the tip of the tooth, whilst the other is set radially to pick up the temperature at the root of the tooth. The gear is rotated between the burners by means of the spindle, and when the tips of the teeth reach the hardening temperature, the oxygen is automatically reduced by a pulsating relay from the first Milliscope so as to prevent overheating, thus allowing the remaining part of the tooth to reach the pre-set hardening temperature. When

(*Continued on page* 184)



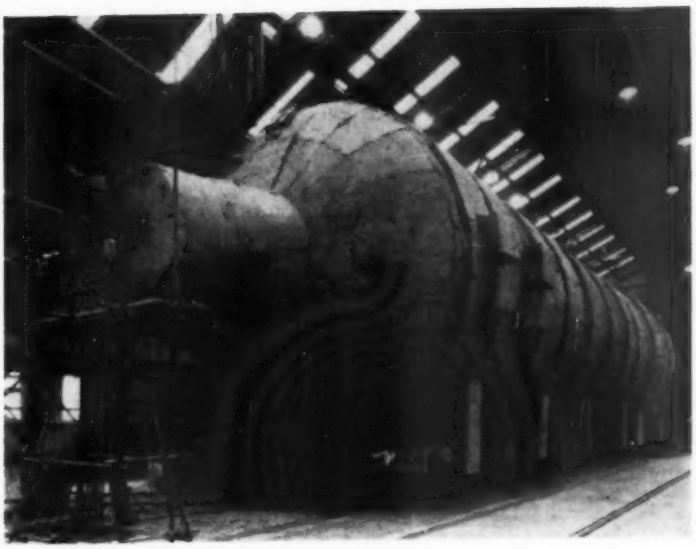
Type LSW machine for flame-hardening the internal gear and roller path of truck frames

Stress Relieving in Situ

Novel Use of Mineral Wool Insulation

By J. W. Dawson

Stillite Products, Ltd.



Courtesy of Head Wrightson, Teesdale, Ltd.

A pressure vessel clad with Stillite mineral wool insulation, and equipped with internal electric heaters for stress relieving.

ONE of the difficulties associated with the fabrication of large steel pressure vessels has been the necessity of relieving the stresses set up by welding. Hitherto, this has ruled out the possibility of site fabrication, which may in the case of projects carried out on remote sites be highly desirable, owing to the problems of transporting bulky and heavy vessels over undeveloped country. Even where well developed transport facilities exist, they are rarely suitable for very bulky vessels.

A good deal of interest has lately been focused on the development of stress relieving techniques in the case of large pressure vessels for the Bradwell nuclear power station. The most noteworthy feature of this project—at any rate from the layman's point of view—was the method of transporting these vessels to Bradwell in Essex from the Teesdale Works at Thornaby-on-Tees of the manufacturers, Head Wrightson, Teesdale, Ltd. The vessels were, in fact, sealed and launched into the river Tees, being subsequently towed by sea to Bradwell—the site of the power station being conveniently near to an accessible beach. Such favourable conditions may not always obtain in the case of other sites selected for nuclear power stations.

The vessels described above were stress relieved by covering them with a suitable thickness of mineral wool insulation, and applying the heat within the vessels by means of electric resistance elements disposed so as to give a uniform dissipation. The merits of this method of heat treatment are considerable. Compared with the conventional technique of placing the pressure shell within a suitable furnace—where one of adequate capacity exists—this new method practically eliminates the very substantial heat capacity of the furnace fabric. Large bulky vessels constitute notoriously uneconomic furnace charges. A typical and very well constructed furnace may require a heat input of 40,000,000 B.Th.U. to stress relieve a charge of 25 tons. Slightly more than 11,000,000 B.Th.U. are in this case usefully employed, the balance representing the normal losses—flue gases, heat capacity of the fabric and surface heat losses.

A specially distinctive feature of stress relieving is the short duration of the operation compared with the time required for the flow of heat through the furnace fabric to reach equilibrium. In the case of a furnace built, for example, with side walls consisting of 9 in. of high temperature insulating firebrick, some 80 to 100 hours may elapse after working temperature has been reached before the walls are saturated and steady heat flow is established. The entire operating cycle could well be completed—from lighting up to final cooling down—in 18 hours, and from this it is clear that the minimum requirements, so far as mechanical stability of such a furnace are concerned, are grossly over-adequate from the thermal and metallurgical viewpoint. It is, of course, true that a furnace designed for stress relieving will usually also serve for normalising, though even here the method of *in situ* heat treatment is quite feasible as will be shown.

The *in situ* method of treatment mentioned above consists of covering the vessel with mineral wool preformed semi-rigid slab and or wire mesh covered mattress of the same materials. These slabs or mattresses are held in position by means of spot welded pins which project from the surface of the vessel through the insulation and engage an outer covering of wire mesh. The ends of the pins are turned down to retain the mesh in position. The insulation is thus sandwiched between the outer surface of the vessel and the wire mesh.

The thickness of insulation required depends to a large extent on the available supply of energy. If this is adequate to raise the vessel to working temperature in, say, 20–30 hours, advantage can be taken of the time-lag in establishing thermal equilibrium in the insulation as described above. Suppose, for example, that it were decided to provide insulation which would allow a heat loss of 100 B.Th.U./sq. ft. hr. at the stress relieving temperature (630° C.), calculations, assuming conditions of thermal equilibrium, would indicate a thickness of about 6½ in. of mineral wool. If, however, this temperature is reached in the short space of time mentioned above, the conditions for which the calculation was made

are not established. The indications are that if the working temperature can be reached in the period stated, 4 in. of mineral wool slab will be adequate. A typical large pressure shell, say 1½ in. thick, may require an energy supply of approximately 0·2 kW./sq. ft. of superficial area: this is equivalent to a heat input of about 680 B.Th.U./sq. ft./hr. The 4 in. of insulation considered would permit a heat loss of approximately 200 B.Th.U./sq. ft./hr. at the relevant temperature, and, of course, under conditions of thermal equilibrium. It may be said, therefore, as a very rough guide, that assuming the energy input is adequate for the rate of temperature rise, the insulation calculated at equilibrium should not pass more than 30% of the total heat input for the entire operating cycle. Clearly, it is an advantage for the insulation to be of the minimum possible thickness, not only from the view point of economy of materials, but also from considerations of cooling rates. Provided the rate of temperature fall permissible from metallurgical considerations is not exceeded, the more quickly this operation can be completed the better. Over-adequate insulation will militate against this, but if the insulation is applied in a number of separate layers, this provides some control over cooling rates, since the outer layers can be stripped off successively without involving a dangerous fall in temperature.

Although the method described is particularly suitable for large vessels, there seems no reason why preformed hoods, constructed from light metal sections and lined with mineral wool insulation, should not be produced for smaller scale work and used repeatedly. For example, a hood constructed of 4 in. mineral wool would have a heat capacity of approximately 560 B.Th.U. /sq. ft. of superficial area. The corresponding figure for a conventional furnace, even if it is constructed most efficiently and fitted with a 9 in. lining of insulation brick, is about 9,000 B.Th.U. /sq. ft. of superficial area. Both these figures, of course, apply to equilibrium conditions at 630° C.

Some mineral wools can be used at temperatures up to 1,500° F. (815° C.). Failure in service when such materials are exposed to higher temperatures for considerable periods is due to fibre embrittlement. Nevertheless, they can be subjected for relatively short periods to much higher temperatures than this. The ultimate fusion temperature corresponding to the temperature mentioned above would probably be in the neighbourhood of 1,430° C. Thus, particularly in cases where the insulation is regarded as expendable, the same arrangement as described for stress relieving could be used for other heat treatment operations, including, of course, normalising.

A logical development of the method outlined above would be the construction of semi-permanent furnaces so that a number of boiler shells, for example, could be treated without the labour of individual lagging and the somewhat higher consumption of materials occasioned by repeated handling. A steel structure adequate in strength to support the necessary insulating material, arranged so as to permit the charging and withdrawal of boiler shells or similar constructions, would constitute the permanent feature of the furnace. Such a structure could be adapted to suit a wide range of shapes and aspect ratios, so as to provide the best features of both this method of insulation and the mode of stress relief in the conventional type of furnace.

Flame-Hardening Excavator Parts

(*Continued from page* 182)

this figure is obtained, the burners are automatically extinguished and the gear lowered into the quenching oil. A flow of compressed air is so directed across the surface of the quenching medium as to eliminate the possibility of igniting the oil. A built-in cooling device, coupled with a pyrometer, maintains the oil at the required temperature. This instrument, by means of a two-way switch, shows the temperature of the quenching oil and of the water flowing through the heat exchanger of the cooling equipment, so that the flow of water may be kept to the minimum consistent with the maximum desirable temperature of the oil.

A flow meter and pressure gauge unit for gas and oxygen is employed so that, together with the Milliscope settings, a method card may be prepared for each type of gear treated. The heating time to harden a spur gear 39 in. in diameter, having 124 teeth of 4 D.P. and a width of 4 in., is approximately 20 minutes if hardening down to the root is required. The gas consumption is about 425 cu. ft. and the oxygen consumption 245 cu. ft. At 1s. per therm, the cost of gas would be 2s. 2d. and oxygen at, say, 40s. per 1,000 cu. ft. would be 10s.

Roller Path Hardening

The automatic oxy-town gas flame-hardening machine Type LSW has been specially designed to harden the internal gear and roller path of truck frames on which the cabin and the excavating equipment rotate. The teeth of the gear are hardened by the progressive method, the burners to which the water spray quenches are attached rising over the length of the tooth. Both flanks of each tooth are hardened simultaneously. The roller path is automatically hardened by the progressive method, the burners and quenches remaining stationary, whilst the component rotates. The speed of rotation is controlled by the Milliscope in order to maintain a constant pre-set temperature.

Blackheart Malleable Annealing Plant

A MAJOR contract of approximate value £120,000 has been awarded to Birlec, Ltd., by Ley's Malleable Castings Co., Ltd., for additional electric furnace equipment for the annealing of pearlitic malleable iron castings from their new mechanised foundry at Derby. With an average output of 1 ton/hr., the plant will comprise three main parts—a high temperature furnace, a fast cooling conveyor, and a low temperature furnace. Both furnaces will be of the type employing pusher mechanisms to progress trays of castings from end to end. Fully automatic means will be employed for transferring castings from the high temperature trays to the cooling conveyor and thence to the low temperature trays. Thus, no manual handling operations will be required between the charge and discharge ends of the line. The trays will be of open type, and scaling of the castings during treatment will be avoided by the appropriate use of a controlled atmosphere.

Niobium (Columbium)—Its Future Prospects

By J. Sandor, D.I.C., A.M.I.M.M.*

Sources of niobium (columbium)—up to recently a less common metal—are now plentiful; rapid strides in methods of ore concentration and in its extractive metallurgy have made the metal and its alloys readily accessible to the designer as an engineering material of importance. There are signs of progress in the development of niobium-based "super alloys" for gas turbine and rocket applications, as well as of its growing use in the steel industry, and in the electronic and nuclear engineering fields. Estimates are given on past and possible future consumption of niobium in its various fields of application and some results of recent research are reviewed.

Historical

SINCE there still appears to be some confusion about the name of this element (atomic number, 41; atomic weight, 92·91; in Group Va in the Periodic Table), perhaps a brief historical note is in order by way of introduction. It was the English chemist, Charles Hatchett, who in 1801 discovered the element and called it "columbium," after Columbia, the "Gem of the Ocean." However, Hatchett evidently analysed the mixed oxide of columbium/tantalum, for it was only a year later that Anders Gustaf Ekeberg, the Swedish chemist, discovered tantalum in a sample of columbite. In 1844, the German chemist Heinrich Rose proved beyond doubt that columbium and tantalum were different elements. He therefore re-named columbium and called it "niobium" (Niobe, the daughter of Tantalus).

A few years ago, the International Union of Pure and Applied Chemistry, with the full support of the American Chemical Society, agreed that the name of the element should henceforth be "niobium." However, many metallurgists, engineers and business men, particularly in the United States of America, are reluctant to adopt the name, and feel that the decision was made by chemists without due regard to the interests of the metallurgical world. This view was reflected by a recent decision of the American Institute of Mining, Metallurgical and Petroleum Engineers (A.I.M.E.), who suggested that the name of the element should be columbium.

Two fundamental difficulties remain, and until these are resolved it is unlikely that agreement will be achieved. The first is that the mineral "columbite" is firmly established in mining, mineralogy and geology. It is argued that it would hardly be logical to change the name "columbium" while it bears such a generic relationship to the name of its chief source mineral, although it would not be unique in this respect (*cf.* tungsten). The second difficulty is that chemical compounds are well-known as "niobates." Even in the United States "niobates" are firmly established and unchallenged as descriptive of compounds of columbium (niobium).

In Britain, many appear ignorant of the fact that the element was originally discovered by an Englishman, and it is even less widely known that it was he who named it "columbium." The fact remains that in Britain, as indeed in most European countries, the name "niobium" has been generally accepted by metallurgists and chemists alike (although perhaps not by columbite producers). In this survey, therefore, "niobium" has been used throughout.

* Warren Spring Laboratory, Department of Scientific and Industrial Research.

TABLE I.—PHYSICAL PROPERTIES OF NIOBIUM

Atomic Number	41
Atomic Weight	92·91
Atomic Volume	10·83 c.c./g-atom
Lattice Structure	body-centred cubic
Lattice Constant	3·294 Å
Ionization Potential	4·01 e.V.
Electrochemical Equivalent	0·1926 mg./coulomb
Density	8·57 g./cm.³
Melting Point	2,468 ± 10° C.
Boiling Point	5,127° C.
Heat of Sublimation	170·9 k.cal./g-atom
Heat of Combustion	2,379 cal./g.
Coefficient of Linear Thermal Expansion	7·1 × 10⁻⁶/° C.
Electrical Resistivity	13·2 microhm-cm. (20° C.)
Magnetic Susceptibility	−2·28 × 10⁻⁶
Tensile Strength (annealed sheet)	20–25 tons/sq. in. (44–50,000 p.s.i.)
Tensile Strength (cold worked sheet	45 tons/sq. in. (100,000 p.s.i.)
Modulus of Elasticity	6·7 × 10³ tons/sq. in.

Few of the so-called "less common" metals have created such interest in recent years as niobium. This was partly due to the United States' stock-piling policy, which created a sudden demand for it at almost any price some five years ago. Meanwhile, its use was severely restricted in the United States by order of the authorities. This concentrated attention by the authorities created something of an aura around this hitherto little known element. But in no small measure the interest has been justifiably based on the fundamental properties of the element niobium (Table I), a metal of high ductility, high melting point, and strength at elevated temperature, as well as other virtues which will be discussed later.

Sources—Present and Future

There is no reason today to regard niobium as a "less common" metal. While admittedly the element niobium is rarely present in an ore deposit at concentrations higher than 0·5% Nb_2O_5, this fact alone no longer constitutes an insuperable obstacle, owing to advances made in mineral processing technology. Moreover, fortunately, in quite a few deposits niobium occurs together with other extractable values such as apatite (raw material for phosphate fertiliser), cassiterite (tin ore), uranium, rare earths, etc.

TABLE II.—PRODUCTION OF NIOBIUM MINERALS [1]
(principal producers only)

Source	Concentrates (long tons)			
	1954	1955	1956	1957
Nigeria				
Columbite	2,914	3,146	2,604	1,923
Malaya				
Columbite	111	236	276	142
Belgian Congo				
Tantalite and Columbite	760	778	611	387
Brazil				
Columbite	193	76	176	—
Norway				
Koppite	175	302	256	—
United States				
Mainly Euxenite	15	6	97	164

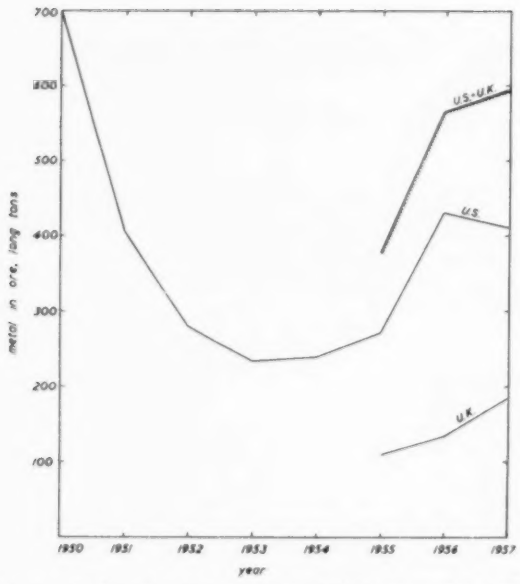


Fig. 1. Estimated consumption of niobium in the U.S.A. and the United Kingdom.

Up to recently, the chief commercial source of niobium has been columbite, recovered as a by-product from tin ores, chiefly in Nigeria. Approximately 80% of the world's production was from this cource (Table II). In columbite, the niobium occurs together with tantalum. The ratio of niobium to tantalum varies widely, but both occur in the ore in the same order of magnitude—generally between 10 : 1 and 1 : 1 Nb : Ta. The close chemical relationship between niobium and tantalum has made separation of the two elements difficult, and this has been a major problem in the commercial extraction of the metal. This obstacle has been overcome, and today there are several competing routes for the preparation of niobium.

During the last decade, significant sources of a niobium-bearing mineral—pyrochlore—have been discovered in many countries. Pyrochlore is essentially a calcium niobate which occurs frequently in carbonatites.* In many carbonatites significant values of radioactive minerals occur in addition to pyrochlore. One important difference between columbite and pyrochlore is that the latter contains much less tantalum in proportion to niobium. In pyrochlore, the Nb : Ta ratio is often as high as 60 : 1. On the other hand, the finely disseminated character of pyrochlore in its host rock has made economic concentration a serious problem. Today, commercial development of two African pyrochlores (Tanganyika and Uganda) is at an advanced stage. Other pyrochlores in many parts of the world are still under early laboratory and pilot plant investigation.

There are two other niobium minerals of interest, i.e., koppite and euxenite. Koppite, a mineral similar to pyrochlore, is being worked commercially in Norway, but on a relatively small scale. A koppite deposit exists also in Western Germany. Euxenite, a complex rare earth mineral, containing uranium and niobium, occurs mainly in North America : it is the object of preliminary laboratory studies in the United States Bureau of Mines.

Two further potential sources of niobium might be mentioned, since these exist in concentrated form. The

* Carbonatites are intrusive calcitic or dolomitic rocks of magmatic and or metasomatic derivation associated with alkaline igneous activity.

TABLE III.—PRINCIPAL SOURCES OF NIOBIUM

Region	Country	Deposits	Reserves (tons)	Nb_2O_5 (%)	Reserves Nb_2O_5 Content (tons)	Reference	Notes
Africa	Nigeria	Tinfields : alluvial and eluvial tin-columbite deposits	—	—	47,000	(3)	Producing
	Nigeria	Kaffo Valley ; granite with uranian pyrochlore	140,000,000	0·26	365,000	*	Not in production
	Uganda	Sukulu ; apatite-rich soil with pyrochlore	200,000,000	0·25	500,000	(4)	Advanced stage of commercial development
	Tanganyika	Mbeya ; carbonatite with pyrochlore	81,000,000	0·33	270,000	(5)	Advanced stage of commercial development
	Kenya	Mrima ; leached carbonatite with decomposed pyrochlore	42,000,000	0·71	300,000	*	Not in production
	Belgian Congo	Ruanda-Urundi and other areas ; tin-columbite-tantalite. Manono ; tin-smelter slags					Producing
	Nyasaland and N. Rhodesia	Carbonatites ; pyrochlore					Not in production
Western Hemisphere	Brazil	Araxa ; pyrochlore	120,000,000	3–5	4,200,000	(6)	Not in production
	Canada	Seven deposits in B.C., Ontario and Quebec ; chiefly pyrochlore		0·25 0·7	645,000	7)	Only small scale commercial production from Bugaboo Creek, B.C. ; one pyrochlore deposit has reached pilot plant stage development
	United States	Arkansas and Idaho ; bauxite and placer deposits			55,000	(2)	Producing small quantities at Bear Valley, Idaho
Europe	Norway	Ulefoss ; koppite	11,000,000	0·2 0·3	35,000	*	Producing
	West Germany	Kaiserstuhl ; koppite					Not in production
Australasia	Malaya	Tinfields ; columbite and smelter slags					Producing small quantities

* Released by official government sources.

TABLE IV.—ESTIMATED U.S. CONSUMPTION OF NIOBIUM
(computed from production of niobium-stabilised stainless steels)

Year	Niobium (Niobium-Tantalum) Consumed in Stainless Steel.		Niobium Consumed in High Temperature and Non-ferrous Alloys.		Niobium Consumed in Miscellaneous Uses, including Carbides and Welding Rods.		Total Ore Consumed (Metal Content)
	(%)	(long tons)	(%)	(long tons)	(%)	(long tons)	(long tons)
1950	80	455	15	85	5	30	700
1951	73	235	17	60	10	30	405
1952	73	165	17	35	10	25	280
1953	73	135	17	30	10	20	230
1954	70	150	20	40	10	20	240
1955	60	125	30	65	10	20	270
1956	60	200	30	100	10	35	430
1957	58	185	31	100	11	35	410
1958 (first 6 months)	58	(95)	31	(50)	11	(20)	(210)

United States' stock-pile contains around 7,000 tons of combined niobium-tantalum oxide.[2] The second source consists of stocks of by-products, mainly niobium oxide, accumulated over the years from the production of tantalum. This by-product may contain around 1,000 tons of niobium oxide.

Large resources of columbite exist in Northern Nigeria, while the known potential reserves of niobium in pyrochlores alone have been estimated to contain over 4 million tons of niobium metal (Table III). Thus, on the basis of present day consumption of niobium in the world (probably under 1,000 tons annum), one need have no worry about the adequacy of reserves within the foreseeable future. This does not mean that all the complex and low grade ores which are included in the known reserves are extractable economically. Indeed, as Table III indicates, only two of the known large pyrochlore deposits have so far reached an advanced stage of commercial development. Research and development is therefore in progress to open up economically the extractable values from others in order to assure a long-term expanding use for niobium.

Consumption

To give an accurate estimate of present-day consumption of niobium in all forms is virtually impossible. Statistics are practically non-existent, and the records of imports of ore invariably quote the combined oxide of niobium-tantalum. Many manufacturers of tantalum import columbites for their tantalum content, and stock-pile the by-product niobium oxide. Columbite with up to 2·5 : 1 Nb : Ta ratio is being imported for this purpose.

A significant point, which merits special attention, is that world production of niobium minerals between 1950 and 1956, was hardly more than 10% over United States' imports.[8] The United States stock-piling programme was discontinued at the end of 1955, resulting in a drastic reduction in United States' imports, which has embarrassed columbite producers throughout the world. United States' imports of all niobium minerals in 1956 were around 5½ million pounds, containing approximately 3¼ million pounds of combined Nb-Ta oxide (1,500 tons). Estimated industrial consumption of niobium in the United States in the same year was considerably lower than that suggested by the import figures. Moreover, it is unlikely that the difference represents ore imports for tantalum production. The estimated U.S. consumption during 1950–58 is shown in Table IV, while Fig. 1 shows the estimated consumption, in terms of metal in ore, in the United States and United Kingdom.

Some explanation is perhaps in order in regard to the estimates presented here. Various sources[9] in the United States have indicated that in recent years, and up to 1957, approximately 60% of the U.S. niobium consumption was in stainless steel, 30% in high temperature and non-ferrous alloys and the remaining 10% in miscellaneous uses, including welding rods and carbides. However, in earlier years, the U.S. Bureau of Mines estimated the distribution to be 73% in stainless steel, 18% in non-ferrous alloys and 9% in miscellaneous uses. Table IV indicates the likely distribution along these lines between 1950 and 1957 in the United States. The figures are computed on the basis of the production of Types 347 and 348 (niobium-stabilised) stainless steel, in each year, assuming that the actual addition of ferro-niobium to the steels was made on the basis of 1·4% niobium (or niobium-tantalum) metal in steel. Thus the

TABLE V.—U.K. STATISTICS ON NIOBIUM

	1950	1951	1952	1953	1954	1955	1956	1957	1958
Imports of Niobium-Tantalum Ores—Concentrates (long tons)	588	558	577	385	306	296	768	447	474
Re-export of Niobium-Tantalum Ores—Concentrates (long tons)	2	20		41	34	28	24	n.a.	n.a.
Consumption of Niobium-Tantalum Ores[10] (long tons—metal content)	n.a.	n.a.	337	191	151	157	258	246	186
Export of Ferro-Niobium, Ferro-Niobium-Tantalum containing more Niobium by weight than Tantalum (long tons)	—	not shown separately	—	—	—	66	163	82	37
Consumption of Ferro-Niobium[11] in Iron and Steel Manufacture (long tons)	n.a.	n.a.	n.a.	n.a.	80	100	170	180	130

— = none n.a. = not available.

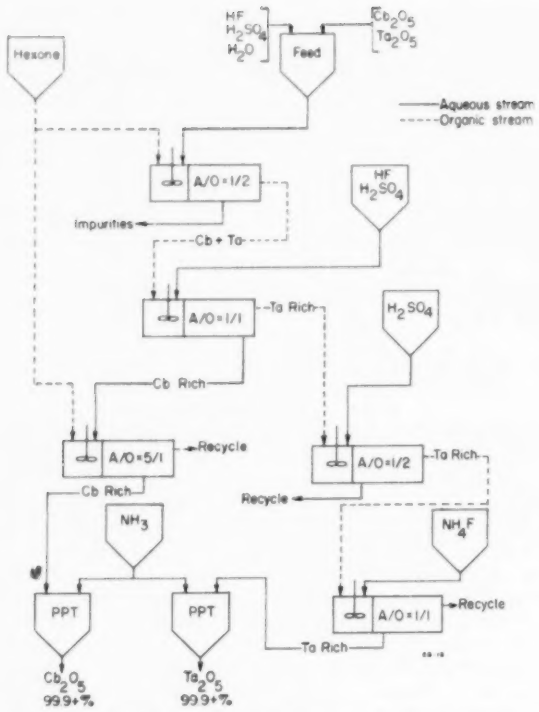


Fig. 2.—HF-H_2SO_4-hexone system for niobium-tantalum separation.

consumptions in the other two sectors are computed from the available data on steel.*

During the Korean war, certain restrictions were in force in the U.S.A. regarding the use of niobium. Although this order was revoked at the end of 1953, niobium has not yet recaptured all the markets which it enjoyed prior to these restrictions, as Fig. 1 indicates.

Unfortunately, statistics on niobium in the United Kingdom are even fewer. The available information (some hitherto unpublished) is shown in Table V. From this it is possible to give an estimate of niobium consumption in the United Kingdom in somewhat simplified terms, and only between 1955–58 (Table VI).

In the following, the prospects of niobium are discussed in each of the three most important fields of application, i.e., (1) steel industry, (2) high temperature alloys and (3) nuclear engineering.

Forecasts of any kind involve certain hazards, but where technology is concerned these hazards are particularly severe. There often occurs a major break-through, the effects of which are impossible to foresee. Such a break-through may occur in an entirely different field of technology and yet have a considerable effect on the one in which one attempts to assess the future.

The situation regarding the future of niobium contains all these hazards. Nevertheless, certain pointers exist today which might warrant another look at this very interesting element. One of these is the recent improvement which has occurred in its availability from readily accessible sources. While only a few years ago niobium had to be carefully conserved and its civilian use severely restricted, lest its important military applications became endangered by scarcity, today the problem is one of over supply. Furthermore, a potential abundance in its supply is virtually assured for the future.

The second important factor favouring its wider application is the rapid progress which has been made in recent years in the extractive metallurgy of niobium, coupled with that which is being made in the technology of concentrating the various low grade ores which are its potential source. This trend will undoubtedly help eventually to make niobium a much cheaper metal, and hence more accessible to the ultimate future consumer.

Advances in Niobium Extraction

(*a*) *Ore Concentration*

The chief commercial means of concentration of niobium ores is by gravity methods. In most areas, alluvial columbite is concentrated in sluice boxes or jigs, followed by a further treatment involving pneumatic tables, and magnetic and electrostatic separation for the removal of monazite and zircon.[12] With the more finely disseminated primary columbites and pyrochlores, the problems of concentration are increased, and research into methods of flotation is in progress at various laboratories. The method employed at Mbeya, in Tanganyika, for the concentration of pyrochlore is based on wet gravity concentration on tables, followed by further upgrading by a combination of flotation and magnetic separation.[13] Conventional methods of mineral dressing are probably employed also for dealing with the pyrochlore in Uganda, but no details have been published. Thus, in dealing with these deposits at least, it has not been found necessary to revert to more expensive chemical processes.

A peculiarity of mineral processing is the fact that each deposit presents its own technical problems of economic concentration. Thus, the solution of pyrochlore concentration in one area is not necessarily applicable to another.

(*b*) *Extraction*

Production of ferro-niobium from the ore concentrate is by aluminium or silicon reduction. No special precautions are needed as a rule to separate the tantalum beforehand, and in fact ferro-niobium produced from columbite contains both niobium and tantalum, in roughly the same proportion as in the ore.

The chemical metallurgy of pure niobium presents many serious problems. The chief one has been the separation of niobium and tantalum oxide. Current industrial practice is based on solvent extraction deve-

TABLE VI.—ESTIMATED U.K. CONSUMPTION OF NIOBIUM

Year	Niobium-Tantalum Metal in Ferro-Niobium Consumed in Iron and Steel Manufacture		Niobium Consumed in Other Uses		Ore Consumed for U.K. Use (Metal Content)
	(%)	(long tons)	(%)	(long tons)	(long tons)
1955	80	65	20	21	107
1956	75	72	25	33	133
1957	78	117	22	32	183
1958	65	85	35	46	138

* In 1957 there was a decline in the United States in the production of niobium-stabilised stainless steels, causing a corresponding fall in niobium consumption. Since this decline was apparently restricted to its use in stainless steel, and since no actual distribution between the various uses in that year is available, the consumption in the other fields was arbitrarily taken as unchanged from the previous year.

The data in the last column of Table IV (consumption of ore on the basis of metal content) was computed on the assumption that the recovery from ore in ferro-niobium for use in steelmaking is 85%, whereas the average overall recovery of niobium from ore for other uses is around 70%.

loped by the United States Bureau of Mines.[14] The system hydrofluoric acid–hydrochloric acid–methyl isobutyl ketone (hexone) has been superseded more recently by one in which sulphuric acid is used instead of hydrochloric acid. It has been claimed that this is a more efficient method in not only separating the two oxides, but also eliminating impurities commonly associated with the ores. The flow sheet in Fig. 2 indicates the major steps involved.

The preparation of niobium is achieved either through the reduction of oxide or of the halides or oxyhalides. The favoured commercial step is a two-stage reduction of the oxide by carbon, i.e.

(1) $Nb_2O_5 + 7\,C \rightarrow 2NbC + 5CO$

(2) $Nb_2O_5 + 5NbC \rightarrow 7Nb + 5CO$

Research is in progress into alternative routes, of which perhaps one of the most interesting is the chloride reduction. Chlorination of the ore, followed by fractional distillation of the chlorides, might be adopted to by-pass the solvent extraction step. Reduction of the chloride may by achieved by hydrogen in two steps,[15] or alternatively in the same manner as for titanium and zirconium by active metal, e.g. magnesium or sodium.

(*c*) *Production of Massive Metal*

The extraction of niobium metal involves techniques which yield a powder, and this still contains minor amounts of deleterious impurities. Melting and powder metallurgy are the two alternatives by which the massive metal can be prepared in pure form.

Of the commercial melting techniques, consumable arc melting has the disadvantage that the impurities cannot readily escape during the short time between melting and solidification. Work is in progress, however, to improve this technique in order to produce commercial purity metal.

The most recent development in this field has been the large scale electron beam melting of niobium, which overcomes the above difficulty. Three inch diameter ingots have been prepared successfully on a commercial scale by this technique, which is capable of further development regarding automatic feeding and control, as well as other refinements.[16] By this technique by far the purest commercially available niobium has been produced to date (Fig. 3).

Consolidation and purification of niobium by powder metallurgy involves prolonged sintering above 2,000° C. and in high vacuum.

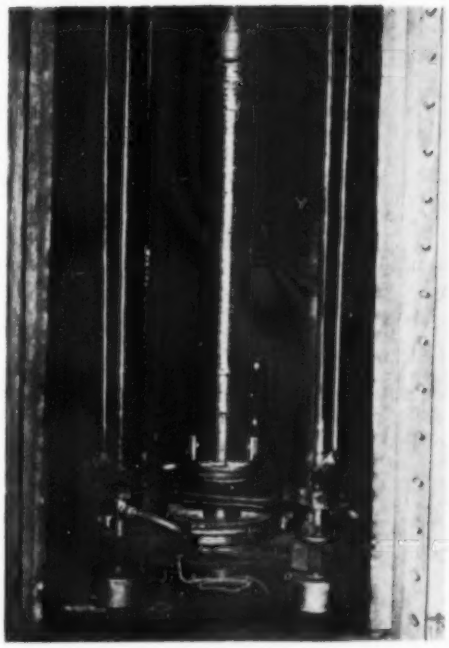
Niobium in Steel

Niobium, when added to stainless steel, prevents carbide precipitation in the 425°–870° C. (800°–1,600° F.) temperature range, preventing inter-granular corrosion

TABLE VII.—U.S. PRICES OF SOME STAINLESS STEELS: DECEMBER 1958.[17]

Type*	Price (cents/lb.)	
	Forging Billets	Bars and Shapes
304 L (Low Carbon) ..	48·25	55·50
316 (Mo)	62·25	73·00
317 (Mo)	76·75	90·75
321 (Ti)	47·00	55·50
347 (Nb)	55·75	64·75
348 (Nb)	61·50	72·00

* See Table IX.



Courtesy of Temescal Metallurgical Corp.

Fig. 3.—An 80 lb. 3 in. diameter ingot of niobium in an electron bombardment furnace at the Temescal Metallurgical Corporation, Richmond, California.

particularly in welded components. Furthermore (again probably because of its action in stabilising carbon), the strength of the niobium-containing stainless steel is improved at high temperature. The minimum niobium-tantalum content of these stabilised steels is of the order of 8–10 times the carbon content. In the United States these steels are designated as Types 347 and 348. In the latter, the tantalum must be held below 0·10%. In the production of niobium-stabilised steels, ferro-niobium or ferro-niobium-tantalum is added to the steel, the recovery being of the order of 85% for niobium and 70% for tantalum. Niobium is not the only element forming stable carbides in steels: titanium-stabilised steel (Type 321) has also been used for this purpose. In particular, during the Korean war, titanium-stabilised steels were substituted in most non-defence applications for the niobium-stabilised type.

There still exists a considerable difference in price in favour of ferro-titanium. In the United Kingdom ferro-niobium is three times the price of ferro-titanium for a lb. of metal (Nb and Ti respectively) contained in the ferro-alloy. Moreover, while niobium must be added to steel to ensure the presence of approximately 10 times the carbon content, 4 to 5 times the carbon content is adequate in the case of titanium. This makes it more difficult for niobium to compete on a cost basis (Tables VII and VIII). However, since titanium oxidises readily,

TABLE VIII.—U.K. PRICES OF SOME STAINLESS STEELS (austenitic (excluding En 54 type); hot rolled bars).[18]

0·3–1·0% Nb.		1·2–1·5% Nb.		0·3–1·0% Ti.	
per ton	per lb. (approx.)	per ton	per lb. (approx.)	per ton	per lb. (approx.)
£333 10 0	3s. 0d.	£357 0 0	3s. 3d.	£315 0 0	2s. 10d.

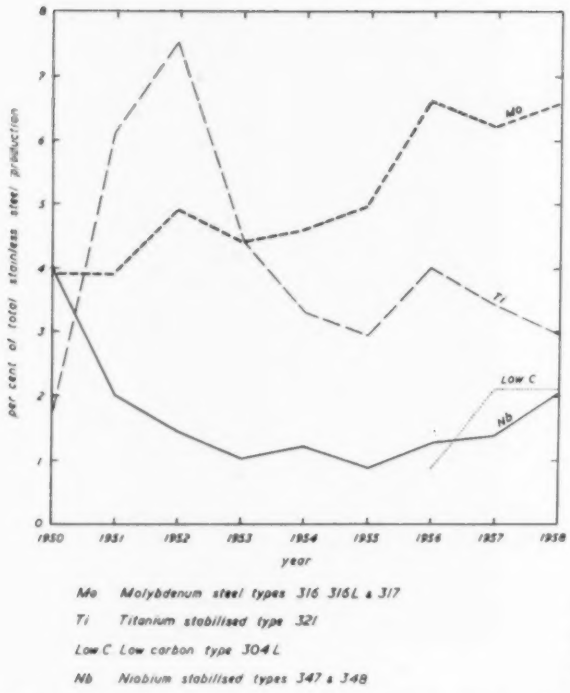


Fig. 4.—U.S. production of certain types of stainless steel.

the steel produced tends to be dirty, inclusions make it difficult to achieve a good finish, causing further difficulty in fabrication. Niobium-stabilised steel, moreover, is stronger at high temperature, casts better and is better also for silver and copper brazing and for atomic hydrogen welding. Finally, mill yield of niobium-stabilised steel is superior.[9]

From the technical point of view, therefore, titanium and niobium stainless steels are not equal, and it is more than likely that a real incentive exists for using niobium-stabilised steel, particularly where quality rather than cost is the main criterion. A decrease in the price differential between ferro-titanium and ferro-niobium should therefore result in a rapid expansion in the use of niobium steel by industry. The size of the possible expansion may be gauged from Table IX, and from the fact that future industrial requirements are likely to be more exacting, requiring more often materials operating at higher temperatures and pressures. This trend should favour the use of niobium steels, as indeed its growing use in the United Kingdom indicates (Table VI).

Another method by which it is possible to reduce susceptibility to inter-granular corrosion in stainless steel is by the removal of carbon to below 0·03%, which is approximately the limit of solid solubility in the 18–8 matrix. In comparison with the stabilised types, however, the strength of this low carbon stainless steel is appreciably poorer, especially at high temperatures. Moreover, according to reports, low carbon steels cause greater refractory damage.[9] On balance, the advent of low carbon steels, with a price similar to titanium-stabilised steels, will create competition in the future with all the alloy-stabilised types, but primarily in the lower priced sectors where requirements are less exacting.

Fig. 4 indicates the production of certain types of stainless steel in the United States as a percentage of the total stainless steel production. A number of significant points emerge from this diagram, and these may be summarised as follows :—

(*a*) During the Korean war the fall in production of niobium-stabilised steel was made up by increased production of titanium-stabilised steels, while by 1952 production of molybdenum steels also began to show a rise.

(*b*) Molybdenum steels, in spite of their higher price, are generally holding on to their gain in popularity whereas titanium steels have declined and appear to continue to do so.

(*c*) Production of low carbon stainless steels shows a sharp increase in 1957.

(*d*) The production of niobium stainless steel, having declined sharply during the Korean war, is slowly but steadily increasing.

(*e*) Although the figures of actual production of niobium steels in 1957 show a drop from the previous year (Table IX), their percentage of the total stainless steel production has continued to increase.

It appears that the continued popularity of molybdenum-bearing stainless steel and the growing popularity of low carbon stainless steel are making it extremely hard for the niobium steels to regain their previous foothold. Nevertheless, the proportion of niobium stainless steel production in the United States today is the same as it was in 1951, at the beginning of the Korean crisis.

The stainless steels shown in Fig. 4 and Table IX represent approximately 9–13% of the total United States' stainless steel production. Moreover, this is an important sector which is expected to grow with the continual advance of technology. A certain amount of competition necessarily exists between the various types shown, resulting in mild fluctuations in normal circumstances. Moreover, a diagram such as Fig. 4 might be expected to reveal advances in stainless steel technology. On the other hand, the sharp peak in 1952 in Type 321 was clearly the result of Government intervention in restricting the use of niobium (incidentally causing a sharp price increase), and would not have taken place otherwise. The diagram appears to indicate that the effect of this has not yet been overcome. With the technical advantages lying so strongly in favour of niobium-stabilised steel, and the apparent willingness of industry to pay for specific quality (as shown by the continued popularity of the more expensive Type 316), it is expected that there will be a further increase in the use of niobium steels in the next few years.

During 1957, there was a remarkable increase in the production of Type 348 niobium-stabilised stainless steel in the United States (Table IX). It has already been mentioned that, according to the specification, the tantalum content in Type 348 must be kept below 0·1%. If, therefore, a columbite ore is used for the production of such steels, its Nb : Ta ratio must be held at 8·5 : 1 or higher.*

Columbites with Nb : Ta ratios higher than 8·5 : 1 have been produced in Nigeria. Pyrochlores are of particular interest, however, on account of their extremely high Nb : Ta ratio. Type 348 stainless steels, or stainless steels with possibly even more rigid requirements in

* A ratio of Nb : Ta = 8·5 : 1 will give a 10 : 1 ratio in steel, since the recovery of niobium is around 85%, while that of tantalum is only 70%.

TABLE IX.—U.S. PRODUCTION OF CERTAIN TYPES OF STAINLESS STEEL: LONG TONS[19]

Stainless Steel Type	1950	1951	1952	1953	1954	1955	1956	1957	1958 (first 6 months)
321 (Ti)	12,649	51,762	63,184	41,535	25,195	32,350	45,348	32,132	10,352
347 (Nb)	32,384	16,894	11,939	9,611	9,419	9,039	13,591	9,728	6,262
348 (Nb)	—	—	—	—	—	—	640	3,422	606
316 (Mo)	29,434	32,600	41,012	41,108	35,158	54,203	69,561	40,030	14,353
316L (Mo)	—	—	—	—	—	—	3,427	13,199	7,055
317 (Mo)	—	—	—	—	—	—	837	5,516	540
304L (low carbon)	—	—	—	—	—	—	9,769	19,889	7,041
Total of All Types	749,078	840,357	857,148	944,169	763,356	1,096,392	1,121,460	937,347	341,261

Type 304L—Stainless steel with C 0·03% max. Type 348—Niobium-stabilised stainless steel with Ta 0·1% max. Type 316L—Molybdenum stainless steel (low carbon).
Type 347—Niobium-stabilised stainless steel. Type 321—Titanium-stabilised stainless steel. Type 317—Molybdenum stainless steel.
Type 316—Molybdenum stainless steel.

regard to freedom from tantalum "contamination," may be needed in the future for applications in nuclear reactors, where the high neutron absorption cross section of tantalum (Table XI) is a serious disadvantage.

A new application for niobium in mild steel was announced recently in the United States. If niobium were added to mild steel in the same amount as to stainless steel, i.e. 8–10 times the carbon content, the cost would be prohibitive for any application in which ordinary carbon steels are used today. It appears from various reports,[20] however, that a trace of niobium (around 0·05%) is adequate to impart certain beneficial properties to mild steel. Advantages claimed for these steels include better weldability and formability, higher strength and toughness, previously obtainable only with higher priced steels. Niobium treatment apparently results in a fine-grained structure in the metal and might be successful in producing mild steel which does not strain age. Up to now attempts to achieve this with other alloying elements have been partially successful only, and almost certainly more costly than the small addition of niobium would be. Its use is expected to be in sheet for deep pressing applications, such as for more complicated shapes in motor car bodies, and also for heavy mobile equipment such as trailers, tractors and trucks.

In conclusion, the outlook for niobium as an addition element in steel making is highly promising. Technical development in every field tends to create a growing demand for materials which have special qualities. In fulfilling this demand, niobium will have to play an increasingly important role in the steel industry. In the final analysis, it is volume production which is of primary importance in the steel industry, and hence the cost of the various alloying elements can be a crucial factor. No doubt a growing market for ferro-niobium and large scale and improved methods in processing the ore will result in further reduction in the price of this important ferro-alloy for the steel industry.

High Temperature Alloys

The second largest use of niobium is as an alloying element in heat resisting alloys (Table IV). So far, in this field the use of niobium has been generally restricted, however, to the role of a relatively minor alloying addition (0·3–5% Nb). Its major effect is to impart creep resistance and to increase high temperature strength; it also improves melting practice. The principal application of niobium-containing nickel-cobalt based alloys is in turbine discs and blades.

Owing to rapidly growing interest in high performance missile and rocket power plants, gas turbine engines and nuclear power systems, there is a strong demand for materials having useful strength, ductility and toughness, coupled with oxidation resistance at very high temperatures. Existing so-called "super alloys" of nickel and cobalt lack the necessary strength above 1,100° C. (2,000° F.), because of their comparatively low melting point. Attention is being centred more and more, therefore, on the refractory metals with melting points above 2,000° C. (3,630° F.). In Table X the various elements of interest are listed in order of their melting point. Only the first five are in the category with melting point higher than 2,000° C. Of these, rhenium is still far too expensive to be considered seriously for the commercial application which is envisaged in the present context.

A very important factor in considering alloys or metals of this kind is their density, which affects the strength-weight ratio. Apart from its effect on economy in general, the question of strength-weight ratio can be a crucial factor in rocket and aircraft applications. Of the four remaining elements in Table X (those in heavy type), niobium has the lowest specific gravity. Niobium's comparatively low density also helps in making it cheaper in all applications where a given volume rather than a given weight must be used. Its present price on a volume basis is less than the other metals in this group, except molybdenum.

Although niobium has the lowest melting point of the refractory metals in this group, its oxide, formed when the pure metal is heated in air to about 600°–1,000° C. (1,110°–1,830° F.), does not "evaporate" like that of tungsten and molybdenum. This fact alone is not sufficient, unfortunately, to impart oxidation resistance to niobium at high temperatures, since its oxide is porous and non-protective. Search is in progress for means to overcome this difficulty.

There are at present two main lines of approach:—

(*a*) by reducing the rate of diffusion of oxygen through the scale to a desired limit by the production of an alloy which would give a tightly adherent, mechanically sound scale;

(*b*) by "cladding" the metal with a layer which would safely protect it for a long period and under severe and repeated thermal shock.

Investigations are still proceeding along these and similar lines: few results have been published so far.

Niobium has a comparatively low elasticity modulus, which may be a disadvantage in certain design applications. On the other hand, other things being equal, a low modulus of elasticity permits more alloying without serious loss of ductility.[21] This provides greater flexibility

TABLE X—PROPERTIES AND COST OF HIGH MELTING POINT METALS

Metal	Melting Point		Specific Gravity	Potential Useful Applications			Price (approx.)		
	(° C.)	(° F.)					Form	($/lb.)	($/cu.in.)
Tungsten	3,400	6,160	19·3	(*a*)	—	—	Powder Sintered bar	3 25–30	18–25
Rhenium	3,180	5,750	20·5	(*a*)	—	—	Sponge Experimental quantities of arc-melted buttons	820–900 830–910	600–670 610–680
Tantalum	2,996	5,416	15	(*a*)	—	(*c*)	Powder Sheet Rod	49 55 60	37
Molybdenum	2,620	4,748	10·2	(*a*)	—	—	Powder Sintered bar	4 25–30	9·5–11
Niobium	2,468	4,475	8·55	(*a*)	(*b*)	(*c*)	Ingot	54–80	16·5–24·5
Zirconium	1,980	3,452	6·4	—	(*b*)	(*c*)	Sponge Sheet, scrap, bar	5 25–35	5·8–8·0
Titanium	1,800	3,272	4·5	—	—	(*c*)	Sponge Billet Bar, rod, plate	1·70 4–25 6–10	0·70 1·1–6·1
Vanadium	1,720	3,128	5·9	—	(*b*)	—	— Ductile	3·50 65–110	14–24
Beryllium	1,350	2,462	1·9	—	(*b*)	—	—	75	5

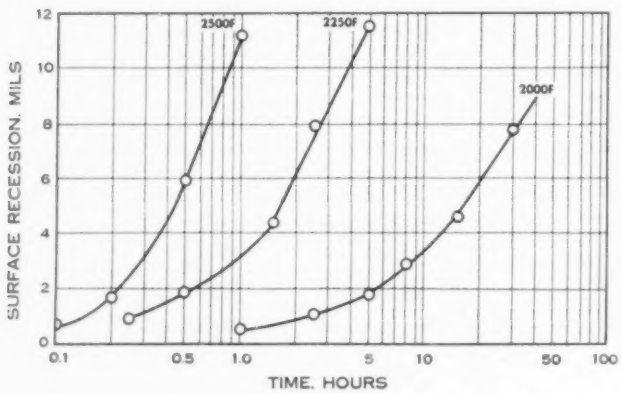
(*a*) = high temperature " super alloy " base. (*b*) = nuclear application. (*c*) = chemical plant.

and much better scope for the development of a suitable niobium-based high temperature alloy. Tolerance to more alloying also gives more scope to the possibility of developing alloys with improved creep resistance and strength at elevated temperatures.

A large number of binary alloys have been thoroughly investigated without much success. Of the ternary systems, promising results have been obtained with a niobium–10% Ti–10% Mo alloy.[22] This alloy, with a tensile strength of 45 tons/sq. in. (100,000 p.s.i.) and 190 B.H.N., is easily worked and is claimed to be amenable to all types of metal forming. It has good oxidation resistance at 1,100°–1,370° C., (2,000°–2,500° F.) for a matter of minutes to some hours (Fig. 5). Its creep-rupture test at 1,430° C. (2,600° F.), measured in air, showed exceptional properties (Fig. 6). Tensile strength in air is 15 tons/sq. in. (34,500 p.s.i.) at 1,100° C., (2,000° F.), and 5 tons/sq. in. (11,000 p.s.i.), at 1,415° C. (2,575° F.). These results are reproduced here merely to indicate that the concentrated effort devoted to niobium, as a promising metal in the high temperature " super alloy " field, is beginning to bear fruit. Meanwhile the workers themselves claim for this alloy no more than that it represents a stage in the progress to date.[22] From the theoretical point of view, there is every reason to press on with these investigations.

No success of any kind has yet been reported in the literature in regard to the development of a diffusion barrier against oxidation at high temperature by coating niobium based alloys. Research is in progress, however, by electroplating and other coating techniques.[23] In this line of approach, niobium has a definite advantage in that its oxide is stable and does not evaporate at high temperatures. There is some hope therefore of modifying the oxide layer by interaction with other substances, or simply by relying on the niobium oxide layer as a substrate for the diffusion barrier.

It is difficult to foresee the prospects of niobium in the high temperature alloy field. If a gas turbine powered motor car were available to the general public in about two to three years time, it would almost certainly create an increased demand for high temperature alloys,—hence for niobium. However, in the beginning, niobium is likely to be a minor constituent in such alloys. It is not possible to make an accurate prediction today concerning the likely demand for niobium, should a niobium-based " super alloy " be developed. If such a new alloy were capable of raising the operating temperature limit in turbines by more than around 100° C. (200° F.), it would almost certainly require a new engine design in order to take full advantage of the development. In this case it may take about five years for the full effect to be felt in regard to niobium requirements. Meanwhile, there will be a growing demand for " super alloys " in rocket and satellite applications, particularly in the high temperature sector. In spite of this, it would be rash to predict a rapid increase in the demand for niobium in the high temperature alloy field within the next five years.



Courtesy of E. I. Du Pont de Nemours & Co.

Fig. 5.—External scaling due to oxidation at 2,000–2,500° F. (1,100–1,370° C) for the niobium–10% titanium–10% molybdenum alloy.

Niobium and Nuclear Engineering

Nuclear development has created a demand for structural materials which must fulfil stringent requirements. A successful " canning " or " clad-

ding " material must be compatible with the fuel element and fission products, and it must preserve its dimensions against the growth and swelling of the fuel. Niobium possesses corrosion resistance, coupled with strengh that elevated temperatures and excellent compatibility with uranium fuels. Its thermal neutron absorption is not as good as that of zirconium or beryllium, but it is still excellent compared with other high temperature materials such as stainless steel (Table XI). Inasmuch as the trend in power reactors is towards higher temperatures to obtain better efficiency, niobium is likely to play a role in this field.

The choice of canning material is rarely a simple one, however. In addition to physico-chemical conditions of environment (pressure, temperature, etc.), the effect of enrichment of the fuel is a vital variable and with it, naturally, the question of cost is the final determining factor. If neutrons are copiously available, the much cheaper stainless steel cladding may be used. On the other hand, the designer may choose to cheapen his fuel investment and spend more on cladding with a low neutron absorber, such as beryllium (or niobium). As always, there is an infinite number of variations and possibilities for future development. For example (as mentioned in the section on " Niobium in Steel "), stainless steel may be alloyed with tantalum-free ferro-niobium to improve neutron absorption, while keeping costs of the cladding material reasonably low.

With high energy fast neutrons, such as in the Dounreay fast breeder reactor of the U.K.A.E.A., the neutron absorption cross section of metals decreases, and the difference in this respect between niobium and such metals as zirconium and beryllium tends to become less important. In the construction of the Dounreay Unit, niobium is in fact being used as a canning material. Niobium's excellent compatibility with the fuel and liquid metal coolant and its good creep strength at the high fuel temperature, must have singled it out for this application.

In addition to structural or canning material, niobium has another important application in the nuclear field as an alloy of uranium for fuel elements. The addition of 10 at.-% niobium to uranium stabilises the *gamma*, body-centred cubic structure of uranium at room temperature. This phase has better metallurgical and chemical properties and far better radiation damage resistance than the *alpha* phase.[24]

So far relatively small quantities of niobium have been used in the nuclear field. According to one estimate,[9] possibly no more than 30 tons of high purity niobium metal may be used annually in this application in the future. On the other hand, the use of stainless steel in nuclear power is expected to grow rapidly. According to one estimate,[9] nuclear power may require 20,000 tons of stainless steel annually in 5 years or so, much of which will be niobium-stabilised. If so, this should provide an important tonnage outlet for niobium.

Other Uses for Niobium

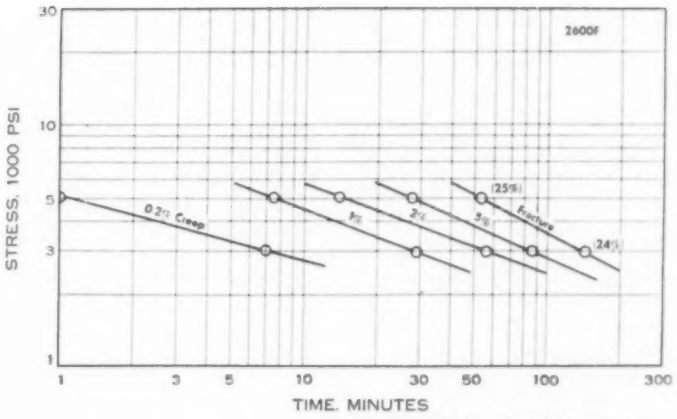
Welding rods, for welding stainless steel, contain niobium, and this accounts for about 4% of total niobium consumption at present. With increased use of stainless steel in structural applications, requirement for welding rods is expected to grow in proportion.

Small amounts of niobium in pellets, strip, or wire, are used as " getters " in vacuum tubes.

Niobium foil (or the carbide) is used for lining crucibles in the melting of metals.[25]

Niobium's corrosion resistance to acids is better than that of zirconium, although it does not stand up to acids so well above 80° C. as tantalum. The ready availability of niobium, and its much lower cost than that of tantalum for an equal volume requirement (Table X), should favour the future application of niobium, wherever possible, in corrosion resistant apparatus.

Niobium is outstanding for service with a number of liquid metals, and in this connection it possesses important potentialities as a future structural material where low-melting liquid metals are used for heat transfer. This potential is at present greatest in the nuclear power field, but other applications may arise in the future in which the high heat transfer coefficient of liquid metal will be utilised.



Courtesy of E. I. Du Pont de Nemours & Co.

Fig. 6.—Stress-time-percentage creep curves for the niobium 10% titanium 10% molybdenum alloy tested in air at 2,600° F. (1,430° C.).

Compounds of Niobium

Niobium carbide is used as a minor addition to cemented carbides.

Niobium boride has been reported recently[26] as a possible application in rocket and gas turbine parts, where corrosion resistance to noxious gases and to liquid or gaseous metal is required.

Niobium oxide ceramics have unusually low values of thermal expansion,[27] and may be useful in certain

TABLE XI.—THERMAL NEUTRON ABSORPTION PROPERTY OF SOME METALS

Metal	Absorption (Barn)
Beryllium	0·009
Zirconium	0·18
Niobium	1·1
Titanium	5·6
Vanadium	6
Tantalum	21
Iron	2·55
Chromium	2·9
Nickel	4·6

applications. Niobium pentoxide is also used as a catalyst in the manufacture of synthetic rubber. The glass and ceramic industries have used some niobium oxide as an additive.

Lead metaniobate is now on the market[28] as a ferroelectric ceramic material for transducer applications in electronics. It exhibits superior characteristics, with an operating temperature range of approximately four times that of barium titanate. It can be used in sensing devices, such as force gauges and accelerometers, which are designed to work at high ambient temperatures, and it permits reliable operation after long periods of time.

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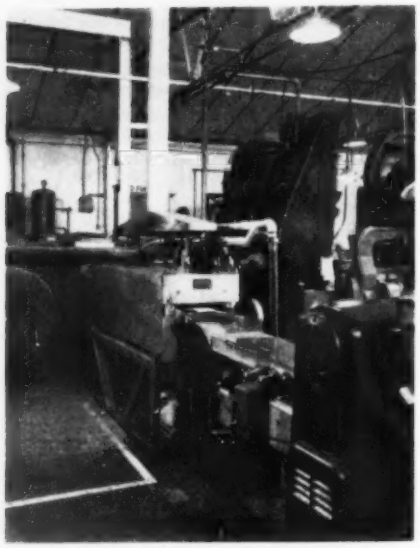
Annealing Extruded Aluminium Tubes

THE installation of conveyor-type furnaces has resulted in increased production of aluminium tubes in the Feltham, Middlesex, factory of Impact Extrusions, Ltd. These tubes are required in hundreds of thousands in various sizes for the packaging of toilet preparations and cosmetics, such as toothpaste and hair cream. They are particularly useful for the marketing and economical use of the more expensive creams, and there is no doubt that new applications will continue to be found.



General view of the furnace.

In the extruded state the tubes would be too hard for satisfactory use, and they are therefore annealed at a temperature of 500° C. Sixty tubes per minute of all sizes up to 1½ in. in diameter are fully annealed in conveyor type furnaces. These utilise high temperature radiant surfaces combined with high velocity air circulation, ensuring rapid heating of the articles passing through the furnaces on a wire mesh conveyor line.

The furnaces are very flexible, adjustments being available for :

(*a*) varying the speed of the belt :

(*b*) varying the distance between the articles and the radiant surfaces : and

(*c*) varying the temperature of the radiant surfaces.

It is, therefore, possible to anneal completely any size of tube with the highest possible economy in gas consumption.

A substantial number of these furnaces have been put into use, both in Impact Extrusions' factory in this country and in associated factories abroad. They were designed, constructed and installed by the North Thames Gas Board.

New Consett Plate Mill

DAVY and United Engineering Co., Ltd., are to build new plate rolling and finishing plant worth over £4¾ million for Consett Iron Co., Ltd. This plant, which is high on the priority list of the British steel industry's current development programme, will add materially to existing British capacity for quality steel plate. It will consist of a 39 in. and 60 in. × 132 in. 4-high hot rolling mill, with a full range of auxiliaries, supported by extensive plate finishing equipment comprising complete heavy and light shearing lines. Steel plate will be produced up to 10 ft. wide and in lengths up to 90 ft., which will be handled and cut to finished size on either the light or heavy shearing lines, according to thickness.

The new plant is due to go into operation in midsummer 1960 and it is interesting to note that it will replace the existing plate mills which Davy-United built for Consett as far back as 1926, and which have worked continuously ever since. This latest order means that Davy-United have now been entrusted with three of the six new plate mills required under present steel industry development plans.

Hacksaw and Magnet Production

Cutlers' Feast Works Visit

Part of the milling section of the hacksaw blade department.

IT has been customary for some years past for the Master Cutler, on the day following the Cutlers' Feast, to arrange for his guests to visit one of the important works of the city to show them the progressive aspect of the Sheffield trades. This year's Feast—the 323rd—was held on St. Patrick's Day, March 17th, and on the morning of the 18th a tour was made of the Napier Street works of James Neill and Co. (Sheffield), Ltd., and of those of the subsidiary company, The Hallamshire Steel Co., Ltd.

This year the Master Cutler is Mr. J. Hugh Neill, deputy chairman of James Neill and Co., and it is of interest to note that three holders of the office of Master Cutler have, within a period of only thirty-five years, been associated with the company, namely the present Master, his father, Sir Frederick Neill (the present chairman), and his grandfather, the late Mr. James Neill (the founder of the business). Furthermore, Mr. G. P. Hunt, then managing director of the Hallamshire Steel Co., Ltd., also held the office during the same period.

The firm had its beginning in the year 1889, when the late James Neill rented a 12-hole coke furnace and commenced the manufacture of crucible steel. Steel-making still plays an important part in the company's success and in the quality of its finished products. Melting of steel is carried out in the three high-frequency melting plants of the company and its subsidiaries. These supply alloy steel for Eclipse hacksaw blades and tool bits, and magnet alloys for Eclipse permanent magnets and magnetic tools: one of the subsidiaries, Composite Steel Works, Ltd., supplies industry with Eclipse steel-faced iron (composite steel), and with Eclipse tool and die steels. Rolling of steel—including ingots melted in the company's own melting furnaces—is carried out in the rolling mills of the company's largest subsidiary (Hallamshire), an old established manufacturer of carbon and alloy steel bars, flats, sheets, and wire rod, which was acquired by James Neill and Co. (Sheffield) Ltd., in 1954.

Time did not allow the visitors to see the whole of the company's activities, the programme being confined to the hacksaw and magnet departments at James Neill and certain of the rolling mills at Hallamshire. An interesting and valuable feature of the arrangements was the presentation to each visitor, as he entered each department, of a coloured card giving brief particulars of the work carried on there. The various processes were numbered and the machines and equipment used for each process were likewise numbered on cards of the same colour. Anyone with experience of trailing round a works at the back of a party and unable to hear the guide will appreciate the value of this system.

Hacksaw Blade Department

The manufacture of Eclipse hacksaw blades commenced in the year 1911, and today they are made in two qualities, high speed steel and low tungsten steel. The former is more expensive but is essential for the cutting of certain hard materials. The low tungsten steel blades are for general purpose use and are made in two types—"All Hard" which, being hardened throughout, provide rigidity in use, and "Flexible" which, being hardened on the teeth only, are less easily broken and are more suitable for the unskilled operator. The steel from which Eclipse hacksaw blades are made is melted by James Neill and Co. (Steels), Ltd., and rolled by The Hallamshire Steel Co., Ltd. After heat treatment, shearing and straightening, it is delivered to the hacksaw blade department in the form of strips.

The first stage in the production of blades from strip is the milling of the teeth, which is carried out on a batch of strips clamped together. To ensure correct tooth form, samples of the milled strips are examined by a projection technique in the laboratory. In the setting operation, whereby side clearance is provided, the milled strip is automatically fed (with magnetic assistance) through a machine which presses one third of the teeth to one side and one third to the other, and leaves one third straight. Two hand hacksaw blades are punched from each double length strip in a single operation which forms the ends, punches the holes and applies the mark "Eclipse" to each blade.

The blades are then heat treated, the details of

A section of the physical laboratory.

temperature, time, etc., varying with the type of blade. The low tungsten steel flexible blades are hardened on the teeth only, being automatically fed by magnetic fingers to the hardening machine, held for a prearranged time with the toothed edge presented to a gas burner, quenched in whale oil, and ejected into a container. In the case of the all-hard low tungsten steel blades, they are assembled in special jigs and then fed through a temperature-controlled gas-fired furnace and quenched in whale oil. Low tungsten blades are packed in jigs and tempered in gas-fired furnaces with a cycle of seven hours.

Gas-fired salt baths are used for hardening high speed steel blades, heating-up taking place in two stages. The first consists of preheating to about 800° C., and the temperature of the blades at the end of the second stage is in the neighbourhood of 1,200° C. Cooling is in air, with a final quench in whale oil which helps to keep them straighter and breaks the scale. The furnace temperatures are rigidly controlled and the whole process follows a specified time cycle. Tempering of high speed steel blades is carried out in electric furnaces with a cycle of 3½ hours. High speed steel blades which have been bent during heat treatment are straightened by manipulation under a jet of fine steel shot.

To reduce the risk of breakage, the ends of the blade are softened ; the low tungsten steel by feeding magnetically on to a band and over gas flames, and the high speed steel by feeding—one end at a time—through an electric furnace.

Finishing operations include paint spraying and marking with transfers the high speed steel blades, and oiling those not protected by painting. The blades are finally fed, in batches of a dozen, to the banding machine, and then packed six bundles to a box.

Hacksaw Frame Department

Eclipse hacksaw frames are made in range of different patterns for use with standard sizes of hacksaw blade, the most recent development being the sheet saw, which looks like a carpenters saw but has a replaceable hacksaw blade at the cutting edge. The saw is made in two models, one for cutting metal sheet and the other for builders' materials.

For the purpose of the visit, the department concentrated on two patterns of frame—the No. 20 T. (the most expensive) and the No. 60 B. (the cheapest). The former has a tubular frame and die cast pistol grip handle, while the latter has a strip frame and a wooden handle in line with the blade. The work seen in this department included the pressing, marking, bending, punching, piercing and grinding, milling, and drilling operations used in the manufacture of the main frame members : turning and screwing small parts; assembly; inspection; and packaging.

Physical Laboratory

Constant metallurgical and physical examination of all cutting tools is carried out in the laboratory, and in the case of high speed steel hacksaw blades, for example, laboratory assistants pick samples at random from each hardening furnace in the blade department on at least eight separate occasions each day. The principal forms of examination are : (*a*) measurement of the hardness ; (*b*) microscopical examination of the grain structure ; (*c*) profile inspection of tooth formation ; and (*d*) measurement of toughness.

In the testing shop the performance of hacksaw blades is measured, comparative tests being carried out between

(*a*) Eclipse blades made in accordance with the current production specification and Eclipse blades

Rolling hacksaw blade sheet.

made in accordance with a specification which differs from it in one respect only, the object being to determine whether the introduction of this single alteration would ensure a better performance ; and between

(*b*) Eclipse blades drawn at random from stock and competitive blades purchased in the open market.

Each test is a strictly comparative one between one blade and another, each blade in turn being set to cut four thin sections of the same bar and on the same machine. Variations in the machinability of the bar are thus shared out, and variations in machine conditions are eliminated completely.

Further sawing tests are carried out, often at the request of individual users, to determine the best way to cut particular materials.

A section of the magnet foundry.

Magnet Department

With the rapid development which has taken place in the sphere of radio, television and electronics, as well as in the ever widening field of use of electric power, there has come an increasing demand for permanent magnets employing new materials and of improved design. The magnets produced by the company today range in size from the small compass magnet to the large magnetron unit made up of sections bonded together, and are supplied for incorporating in such products as telephones, meters, thermostats, electrical instruments, lifting and holding devices, magnetic separators, radio and television, generators and magnetos, and automatic train control. Special attention has been directed over the years to the development and manufacture of magnetic work-holding devices for industry, and the experience of the company in the properties and applications of permanent magnets is reflected in the variety of magnetic work-holding and feeding devices seen in passing through the works.

The output of the department is about half a million magnets per month, but in the time available visitors were only able to see certain selected processes. The first of these was the production of castings in Alni, Alnico and Alcomax (alloys of aluminium, nickel, cobalt and iron). The metal is melted in high frequency furnaces, and subsequently cast at temperatures in the range 1,630—1,680° C. into accurately prepared moulds. In many cases the moulds are a combination of shell and sand moulds—one half in each. After breaking the magnet castings from their runners, adhering sand is removed by shot blasting, and later they are cleaned again to remove scale after heat treatment. Removal of surface roughness by hand grinding facilitates the main grinding operations on larger machines, when many castings can be ground at one time.

The main grinding operations include rough grinding, precision grinding and duplex grinding. To ensure maximum machine utilisation in rough grinding, female assistants are employed for all work except actual grinding, when each operator has a 35 h.p. motor under his control. Duplex grinding is used where magnets require two parallel faces grinding. This is achieved in one operation, at great speed, by passing the magnets between two hydraulically controlled grinding heads. Permanent magnets are used in certain operations for holding the workpieces, and also for continuous cleaning of the coolant. The methods of gauging employed are the result of time and motion study, and are aimed at simplifying procedure, reducing fatigue, and facilitating selection of work to required specifications.

Full magnetic characteristics are rapidly determined with special test panels capable of accomodating a wide range of magnets. In some cases adequate control can be effected with fluxmeter measurements, or by lifting weights. Whilst all magnets are magnetised for testing purposes, the majority are despatched in the demagnetised state, to facilitate correct assembly and subsequent magnetisation at the customer's own works.

Rolling Mills

The visit to the Hallamshire Steel Co., Ltd., was confined to three sections : (*a*) the hot wire rod mill ; (*b*) the hot bar mills ; and (*c*) the Nos. 1 and 2 hot sheet mills. All cater primarily for the production of high speed, stainless and other alloy steels, as well as special carbon steels. In the rod and bar mills the materials produced are mainly for use in the automobile, aircraft, engineering, agricultural implements, textile machinery and tool making industries, whilst the output from the sheet mills is principally used for the production of metal cutting saws, including hacksaw blades, and other cutting tools.

For the production of wire rod in high speed, stainless and other alloy steels, and special carbon steels, in coils, the raw material, in the form of billets is first fed by mechanical pusher into a temperature-controlled producer-gas-fired reheating furnace. The hot billets are given an initial rolling in the three-high 14 in. cogging mill to prepare them for further processing. Before final rolling, further reduction in size is carried out in a two-stand three-high 14 in. intermediate mill. The finishing mill has 10 in. rolls, and the material may pass through a series of up to ten three-high stands. The mills and ancillary equipment are electrically driven.

The output from this mill is supplied to wire drawers and cold rollers for further processing. Rounds range from 0·212 in. to 0·718 in. ; squares from 0·212 in. to 0·562 in. ; flats from 0·370 × 0·100 in. to 1·250 ×

0·375 in.; special shapes are also produced. All sizes and shapes are finally coiled.

Plant for hot rolling bars comprises a series of six separate mills. With the exception of No. 4 mill, which is two-high, all the mills are three-high. No. 1 mill has five stands and 12 in. diameter rolls, No. 2 mill four stands and 12 in. diameter rolls, No. 3 mill four stands and 12 in. diameter rolls, No. 4 mill five stands and 14 in. diameter rolls, No. 5 mill five stands and 8 in. diameter rolls, and No. 6 mill four stands and 10 in. diameter rolls. The mills and ancillary equipment are electrically driven.

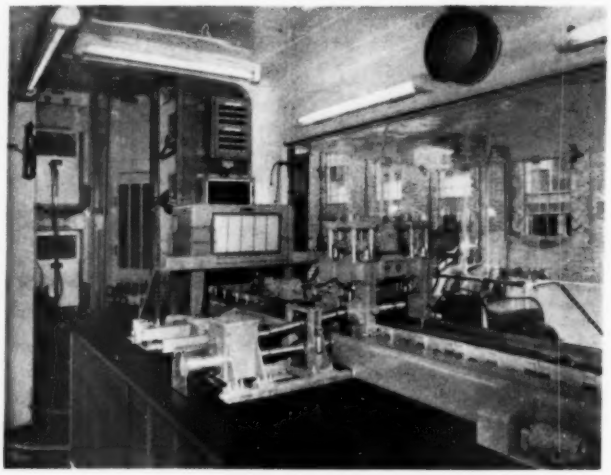
Bar sizes covered by the mills are as follows: rounds from 0·250 in. to 6·00 in.; squares from 0·250 in. to 4·00 in.; hexagons from 0·250 in. to 3·812 in.; octagons from 0·250 in. to 2·125 in.; and flats from 0·375 in. to 9·00 in. wide × 0·62 in. to 3·00 in. thick (according to width): special sections are also produced. After rolling, most bars are transferred to the heat treatment department for annealing, or hardening and tempering, as required. In certain cases, bars rolled in these mills are passed to the cold (bright) drawing, turning and centreless grinding departments for further processing.

In the hot sheet mills, flat ingots or slabs are rolled into sheets, first being taken to an intermediate stage and then, after annealing where necessary, being descaled by shot blasting prior to finish rolling. The Nos. 1 and 2 sheet mills seen by the visitors have 20 in. diameter rolls in four two-high stands. A further four sheet mills are situated in another section of the plant. After rolling, the sheets may be subjected to one or more of the following operations: (*a*) annealing; (*b*) final descaling; (*c*) paring to exact length and width, and (*d*) mechanical cold flattening.

Rolling Mill Control Demonstration Van

A DEMONSTRATION van showing how a complete rolling mill can be controlled automatically, is at present on a six-month tour of major steel works and non-ferrous works in the U.K. Demonstrations and lectures are being given at universities in the areas visited as well as at works. The van, which has been fitted out by The English Electric Company's Metal Industries Division, contains a working model of a rolling mill, on a scale $\frac{1}{8}$ in. to the foot. The model is controlled by full size automatic equipment.

Demonstrations and talks are given at each centre by a team of experts led by Mr. D. W. Kilby, of the Company's Stafford Works, and including Mr. K. A. Hall (Sales Manager, Metal Industries Division), Mr. H. S. Brown (Chief Engineer, Metal Industries Division), and Mr. D. S. Apps (Contracts Manager, Metal Industries Division). The demonstrations show how the various operating movements on a rolling mill can be sequenced and controlled automatically. These sequences or "rolling programmes" are stored, and can be selected by switches and set to work by a push button.



General view of the interior of the van.

In the majority of steel works at present, the operations on a mill, such as the movement of the roller tables carrying the stock, the adjustment of the distance between the mill rolls, the manipulation of the stock into the right rolling channel, and the main mill drive itself, are all controlled manually. The development of equipment which enables the complete operation to be carried out automatically by pressing a push button is a major step forward in the automation of rolling mills. The equipment has been developed and modified by the Company from an original idea of the British Iron & Steel Research Association. The heart of the programming equipment is a device called a translator unit and the Company has been licensed by B.I.S.R.A. to use the unit in its original or a modified form. The equipment demonstrated by the English Electric van is now available for use in the steel industry. It is already installed at a mill in the U.K., and other installations are going in. The benefits of automation are a more consistent quality of the rolled metal, higher productivity, more efficient use of operators and less maintenance work on the mill.

Southern Instruments, Ltd.

SOUTHERN INSTRUMENTS, LTD., announce the formation of an Analytical Instruments Department, which will sell equipment designed and manufactured within the Company, and also sell, and in some cases manufacture, equipment of outside design. Further developments will follow in the polarographic field in which the Company is already well-known for its cathode ray polarograph. Among the electronic analytical tools which will become available in the future, is the Sigrist and Weiss (Zurich) photometer, which is suitable for both laboratory and industrial measurement of absorption and turbidity. Mr. W. B. Horner, formerly Sales Manager of the Company, has been appointed General Manager of the Analytical Department, and will be assisted by Mr. G. B. Thorpe, late of Plessey, on Technical Sales, and by Mr. J. Hetman, on Applications Research.

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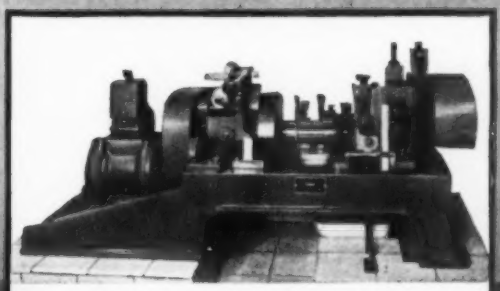
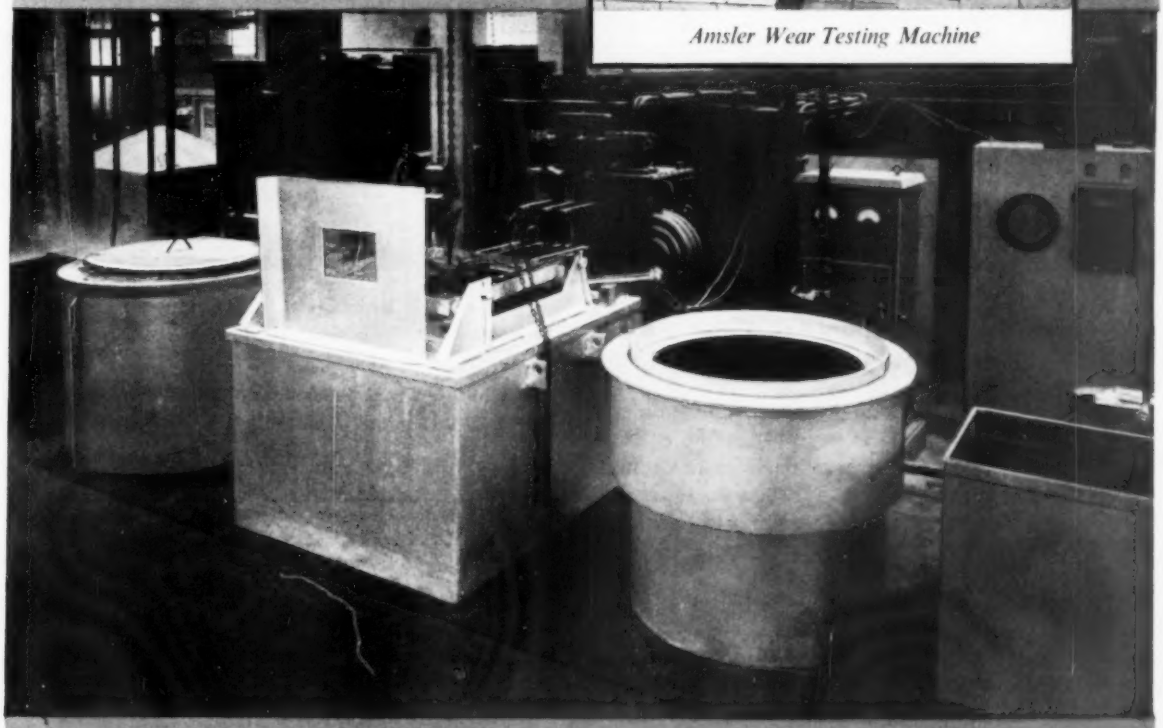


Amsler Wear Testing Machine



Electrically-heated 'Sulfinuz' Salt Bath Furnace

The 'Cassel' 'Sulfinuz' Process uses a salt bath at 570°C. to impregnate the surface of steel or cast iron with sulphur and nitrogen.

For information on 'Sulfinuz' treatment and other salt bath processes, consult the 'Cassel' Heat-Treatment Service.

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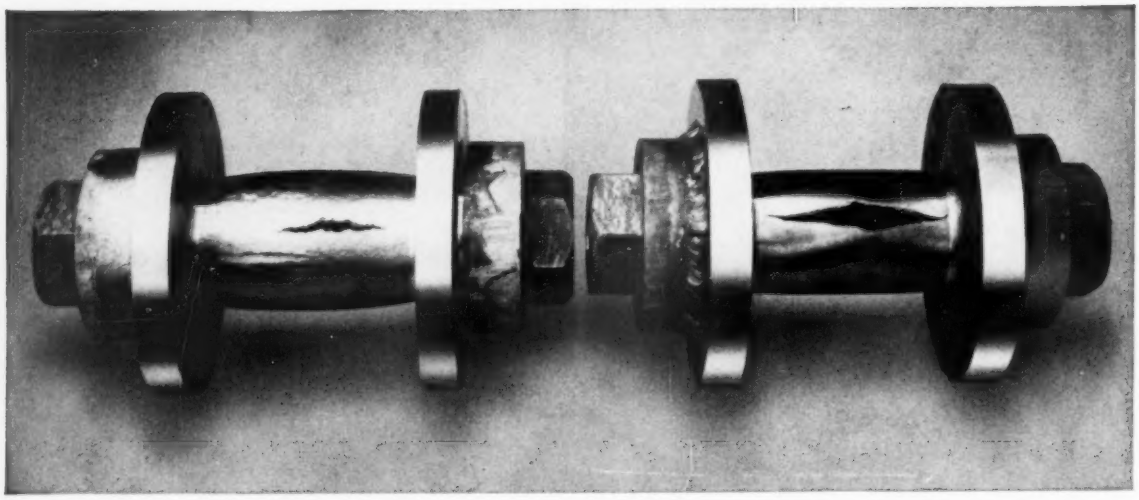

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LEFT *Gun-metal* **0·25 in.** *thick—burst at 4480 lbs. per sq. in.*

RIGHT *Aluminium-bronze* **0·10 in.** *thick—burst at 4816 lbs. per sq. in.*

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NEWS AND ANNOUNCEMENTS

Institute of Metals

Election of Officers

The following members have been elected to fill vacancies on the Council of The Institute of Metals and will take office as from April 14th, 1959:

President: G. L. Bailey, C.B.E. (Director, The British Non-Ferrous Metals Research Association).

Past-President: Marshal of the Royal Air Force The Lord Tedder, G.C.B. (Chancellor, University of Cambridge; Chairman, Standard Motor Co., Ltd.).

Vice-Presidents: H. Ford (Professor of Applied Mechanics, Imperial College of Science and Technology, University of London); E. H. Jones (Joint Managing Director, Capper Pass and Son, Ltd., North Ferriby); and H. O'Neill (Professor of Metallurgy, University College of Swansea, University of Wales).

Honorary Treasurer: D. P. C. Neave (Director, The British-American Metals Co., Ltd.; Capper Pass and Son, Ltd.; James Bridge Copper Works, Ltd.; and Wolverhampton Metal Co., Ltd.).

Ordinary Members of Council: W. O. Alexander (Assistant Research Manager, Imperial Chemical Industries, Ltd., Metals Division, Birmingham); N. P. Allen F.R.S. (Superintendent, Metallurgy Division, National Physical Laboratory, Teddington); F. Dickinson (Manager, Development and Research Department, The Mond Nickel Co., Ltd., London); and L. Rotherham (Research Member of the Central Electricity Generating Board, London).

Medal Awards

The Council of The Institute of Metals has made the following awards of medals:

The Institute of Metals (Platinum) Medal to Dr. L. B. Pfeil, O.B.E., F.R.S. (Director, The Mond Nickel Co., Ltd.) in recognition of his outstanding contributions to non-ferrous metallurgical science and to the non-ferrous metals industries.

The Rosenhain Medal to Professor R. W. K. Honeycombe, (Professor of Physical Metallurgy, University of Sheffield) in recognition of his outstanding contributions in the field of physical metallurgy.

The W.H.A. Robertson Medal and Premium to Dr. R. B. Sims (Chief Engineer, Davy and United Engineering Co., Ltd.) for a paper on "Automatic Gauge Control in Rolling Mills," published in the *Journal of the Institute of Metals*, 1957–58, vol. 86.

British Foundry Exhibition

Britain's first-ever national exhibition devoted solely to the foundry industry will be held in Birmingham from May 21st–30th, when the city's Bingley Hall will house the biggest concentration of exhibits and displays of foundry plant, equipment and supplies to be assembled as a collective indication of the industry's strides in mechanisation, mechanical handling and modernisation generally. Nearly 100 firms specialising in the manufacture and supply of foundry requisites will take part, and with many working exhibits the famous exhibition hall will take on the appearance of a big industrial plant. Special measures have been taken to enable furnaces to be used and molten metal to be handled, and leading British technical experts expect to welcome foundrymen from all parts of the world.

The exhibition, which is sponsored by the Foundry Trades' Equipment and Supplies Association, Ltd., will not be open to the general public. Admission will be by ticket or trade card presented at Bingley Hall, between 10 a.m. and 6 p.m. each day, with the exception of Sunday.

Institute of Welding Spring Meeting

Two subjects of considerable topical interest will be discussed at the Spring Meeting of the Institute of Welding, to be held in London from Monday, April 20th, to Friday, April 24th. At the technical meeting on the morning of Wednesday, April 22nd, the theme will be "Low Temperature Properties of Aluminium Alloys," and the following papers will be presented:

Low Temperature Properties of Welded and Unwelded Al–5% Mg Alloy Plates, by J. E. Tomlinson and D. R. Jackson;
Extruded Aluminium Alloys for Low Temperature Service, by R. J. Durham;
Tear Tests on Aluminium-Magnesium Alloy Plate, by J. Sawkill and D. James; and
Low Temperature Properties of Aluminium-Magnesium Alloys, by R. E. Lismer.

At Friday's technical session, also commencing at 9.30 a.m., the "Economics of Welding" will be discussed, with some emphasis on welding for the structural industry. The papers to be presented are:

A Survey of the Present Position on the Economics of Welding, by A. G. Thompson;
Dynamics of Welding Production Management, by D. M. Kerr;
Economics of Multi-Spotwelding, by M. H. Lummus; and
Structural Applications of Stud Welding, by R. W. Taylor and J. C. Chapman.

Because the Meeting, which opens with a reception at the Institute on the Monday evening, is being held during the Engineering, Marine, Welding and Nuclear Energy Exhibition at Olympia, the technical discussions are confined to morning sessions, to enable members to attend the Exhibition in the afternoon and evening. On the Tuesday and Thursday, there will be a choice of works visits around London, and on Wednesday evening, the North and South London Branches of the Institute are holding their Joint Annual Dinner at the Connaught Rooms.

Graduate Course in Mechanical Working

Graduate courses in selected fields of industrial metallurgy are now available at the University of Birmingham. Following the success of the course in foundry science and engineering, held in the session 1958–59, it is proposed to hold a course dealing with the mechanical working of metals in the session 1959–60. It is planned to repeat these courses every two or three years.

The new course is designed for science graduates who are working in, or proposing to enter, those branches of the metallurgical industry which are concerned with metal working. It will be of nine months' duration, leading to a Diploma in Graduate Studies; or of one year's duration, leading to an M.Sc. degree. The course has been planned to provide about ten lectures each week dealing with fundamental knowledge of the deformation

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of metals, the metallurgy of deformation processes, the general theory and practice of industrial metal working processes, production engineering, process control and statistics. The remaining time will be spent in laboratory work, seminars, discussions and works visits.

The normal entrance qualification for the course is a suitable degree in metallurgy, physics, or engineering, or an equivalent professional qualification. Further information about the course may be obtained from the Secretary of the Department of Industrial Metallurgy, The University, Edgbaston, Birmingham, 15.

Arc Welding Conference

ORGANISED by the Department of Industrial Metallurgy, a Conference on The Electric Arc in Welding will be held at Birmingham University, on Thursday, June 25th, 1959. Following an opening address by PROFESSOR E. C. ROLLASON, the following papers will be presented for discussion :

MORNING

A Survey of Arc Characteristics and their Significance in Welding, by Birmingham University Joining of Metals Team (presented by D. R. MILNER) ;

Gas Absorption from Arc Atmospheres, by Birmingham University Research Team (presented by DR. G. R. SALTER) ; and

The Mechanism of Metal Transfer in the Welding Arc, by Electrical Research Association and Birmingham University Research Groups (presented by J. C. NEEDHAM).

AFTERNOON

Heat Transfer from Arcs, by Birmingham University Research Team (presented by J. B. WILKINSON) ; and

Plasma Projectors and Constricted Arc Torches—their Design, Characteristics and Application, by A. R. Moss, Ministry of Supply, Armament Research and Development Establishment.

An enrolment fee of £1 1s. 0d. will be charged, which will include the cost of lunch and refreshments. Further particulars and forms of enrolment may be obtained from the Secretary, Department of Industrial Metallurgy, University of Birmingham, Edgbaston, Birmingham, 15 ; the envelope should be marked " Welding Conference."

Aluminium Street Lighting Column Design Competition

ALUMINIUM street lighting columns have been in service for many years in America and have recently been introduced on the Continent and in this country. The Aluminium Development Association feels that the time is ripe to encourage the evolution of good designs (taking especially into account aesthetic appearance, economy of construction and the advantages of aluminium) for such columns and the eventual wider adoption of them in the United Kingdom. Accordingly, the Association announces an open competition for entry by lighting specialists, architects, industrial designers, engineers and other individuals or groups. The competition is for the design of either a 25 ft. high column for Group A : trunk road lighting ; or a 15 ft. high column for Group B : non-trunk road lighting.

Three prizes of £250, £100 and £50 are offered, together with an additional student's prize of £75. Three assessors—The Hon. Lionel Brett (nominated by the President of the Royal Institute of British Architects), Professor Sir Alfred Pugsley, O.B.E., F.R.S. (Past-President of the Institution of Structural Engineers), and Sir Gordon Russell, C.B.E., M.C. (Director of the Council of Industrial Design)—will be assisted by a panel of technical advisors.

The closing date for receipt of entries is July 1st, 1959. Copies of the competition regulations and conditions (with specification and design requirements) and of the entry form may be obtained from the Secretary, The Aluminium Development Association, 33, Grosvenor Street, London, W.1.

Technical Paper Competition

WITH the object of attracting papers suitable for presentation at Annual Conventions and/or for publication in appropriate journals, thus increasing the technical matter made available to the industry, the National Association of Drop Forgers and Stampers is offering prizes for written papers under the general title of " Production and Processing of Forgings." Three prizes will be awarded, with a maximum first prize of £50, the amount awarded being dependent on the merit of the paper concerned. The paper submitted must not be less than 3,000 words in length and it is recommended should not exceed 5,000 words.

In order to save unnecessary work on unsuitable subjects, participants should send to the Technical Officer of the Association, at 245, Grove Lane, Handsworth, Birmingham, 20, the title and a brief synopsis of the paper, when they will be advised as to its suitability. Further particulars with regard to the rules governing the competition should be obtained from the Technical Officer, at the above address.

School of Welding Technology

THE School of Welding Technology, founded in October, 1957, has now organised twenty special day and evening courses which have been attended by more than 1,000 engineers, designers and draughtsmen from firms anxious to develop to the full the advantages offered by welding and welded construction. The demand for places has been such that two full-time courses are now being offered each month ; in all, thirty separate courses covering the principal branches of industry are available.

Courses to be held during the next six months include :

Health and Safety in Welding (18th April).
Welded Structures (27th April–1st May).
Metal Spraying (4th–6th May).
Ultrasonic Inspection (25th–28th May).
Brazing Technology and Design (8th–12th June).
Welded Design and Construction in General and Mechanical Engineering (22nd–26th June).
Advanced Course for Welding Engineers (22nd–30th September).
Welded Design and Construction of Pressure Vessels and Pipework (12th–16th October).
Control of Distortion (26th–28th October).
Residual Stresses and Stress Relief (29th–30 October).

Further particulars may be obtained from The School of Welding Technology, 54, Princes Gate, London, S.W.7.

Carbodrip Price Reduction

WILD-BARFIELD ELECTRIC FURNACES, LTD., announce a reduction in price of their patented Carbodrip gas carburising fluid in the United Kingdom, as from March 9th, 1959. This reduction follows a fall in the cost of raw materials, and will result in even greater savings in operating costs by users of Carbodrip in drip feed gas carburising furnaces.

Electrical Aids in Industry *Data Sheet* **No. 4**

Resistance Heating-1

In this form of heating, the heat is produced by passing an electric current through a high resistance conductor which is termed the " heating element ".

The heat is transferred from the heating element to the work by convection, radiation or conduction, or by a combination of any, or all of these. When it is a question of radiation or convection, the element can be a bare wire or strip of suitable material, provided it is adequately supported on electrical insulation capable of withstanding the temperature.

When there is to be contact between the work and the element, heat being transferred to the work by conduction, the wire or strip must be surrounded by suitable insulating material and enclosed in a protective sheath.

In the majority of cases, the wire or strip forming the heating element is made of a nickel-chromium alloy which has a high electrical resistance and can be safely used in air at temperatures of up to 1050°C., or in a suitable atmosphere, of up to 1150°C. Other element materials are available for use at higher temperatures.

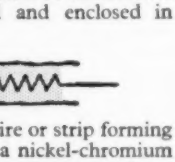
Sheathed elements, essential for contact heating but also used widely for convection and radiation heating because of the convenience afforded by the mechanical strength of the sheath, usually metallic, and by their "built-in" electrical insulation, cannot be used at temperatures as high as the bare wire or strip. This is because the wire, being embedded in insulation, is always at a higher temperature than the sheath, and to keep the wire temperature down to a safe figure the sheath temperature is usually limited to a maximum of around 800°C.

Automatic temperature control of resistance heating elements within narrow limits is easily effected, but if manual control only is desired, devices are available which enable the heat output of the elements to be controlled precisely at a required level. As with all electrical methods, a time switch may be included in the control circuit for automatically switching on or off at predetermined times, and this can enable, for example, an electric oven to be fully up to working temperature by the time the working day starts. Since there are no combustion products from the heaters, there is no need to build flues or special ventilating arrangements which also carry away useful heat.

Electric resistance heating may profitably be put to many diverse uses; two of these are described briefly below, others will be listed in a subsequent data sheet.

Furnace Heating

Electric resistance furnaces can be divided into two main categories, batch type and continuous. In most cases, the heating elements are of nickel-chromium alloy, for furnace temperatures up to around 1050°C., but higher temperatures, up to nearly 3000°C., can be obtained by using other metals or alloys, or in some cases non-metallic elements. A protective atmosphere is desirable to prolong the life of some of these higher-temperature elements. For all temperatures, electric resistance furnaces can be constructed so that the heating process takes place in a controlled atmosphere if this is dictated by the composition or heat requirements of the work charge. In some furnaces, fans are used to circulate the air or special atmosphere over the charge, thereby giving increased heating rates and a uniform temperature over the whole charge.



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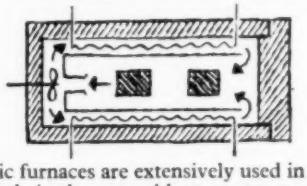

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Oven Heating

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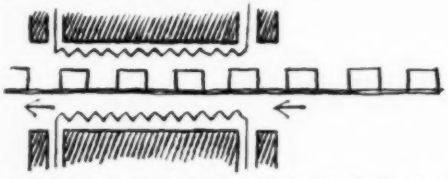

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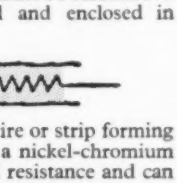

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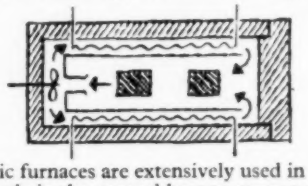

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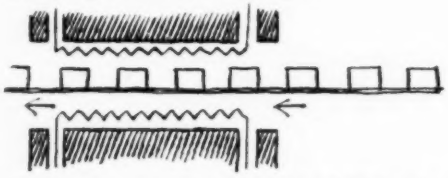

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RECENT DEVELOPMENTS
MATERIALS : PROCESSES : EQUIPMENT

Automatic Bundling of Bars

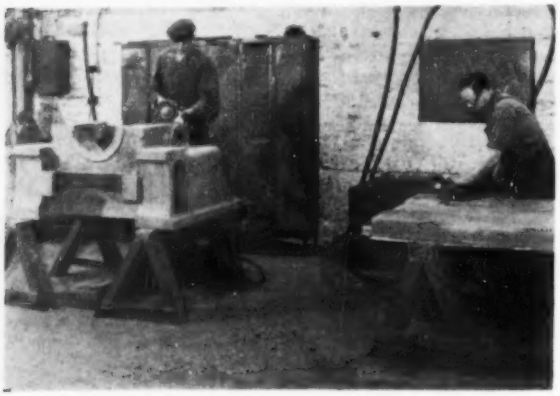
In most rolling mills, bars are still bundled by hand. This procedure, especially in merchant mills of high productive capacity, requires extensive equipment and many bundling operators. Schloemann have recently developed a machine which enables the bundling of bars to be carried out fully automatically.

Features of this machine, which has already proved itself in test operation, are simple design, good accessibility, reliable operation, and high bundling capacity. The machine bundles bars into packages from 50 to 300 kg., and the bundle diameter and length of bar may be varied within given limits. The material to be bundled is entered between two arms, which carry the tying wire. It is therefore unnecessary for the wire to be placed around the bars prior to completing the bundle. Bundling the bars, twisting the wire, and cutting off the finished bundle is carried out in quick succession, each individual operation partly overlapping the next in time sequence.

Schloemann, A.G., Dusseldorf, Steinstrasse, 13, Germany.

Foundry Dust Control

The Dustuctor Co., Ltd., a member of the Holman Group, has successfully developed a highly efficient method of extracting at source harmful respirable dust and removing it from the breathing area of the operator. The low volume, high velocity system is particularly important because of the extensive use of high speed portable power tools such as sanders, grinders and cutting-off wheels, which create large volumes of dust in foundry fettling shops, engineering works, etc. The Dustuctor system operates by attaching an extractor to the hand tool near the source of the dust, and a suction is created (a depression of 5 in. Hg.) which extracts approximately 35—40 c.f.m. of free air through the extractor head. A high speed turbo-exhauster creates the suction and a $\frac{3}{4}$ in. diameter flexible hose is taken from the extractor head to the filter unit. In the accompanying illustration taken in the fettling shop of Metropolitan-Vickers Electrical Co., Ltd., in Trafford Park, hand tools using the Dustuctor system can be seen working on castings. The grinder on the left employs an extractor head, and that on the right is fitted with a cowl.

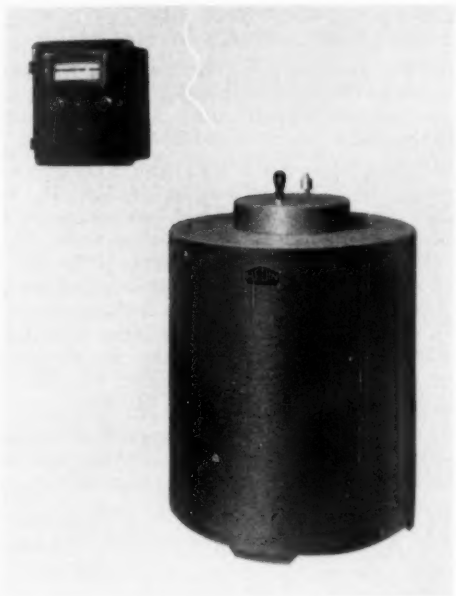


The Dustuctor Co., Ltd., Camborne, Cornwall.

Electric Melting Furnace

The electric resistance melting furnace recently introduced by Hedin, Ltd., has been designed to meet a growing demand for small melts for the special alloying of non-ferrous metals in quantities of up to approximately 100 lb. The illustration shows a typical lift-out crucible type, which will melt 50 lb. per charge. It is rated at 14 kW., the economics being 10 lb./kW. The furnace has a temperature range of 1,400° C., and artificial atmosphere inlets are provided to prevent oxidation during the melting cycle. The atmosphere may be piped from a gas generator or from cylinders.

Further advantages claimed are that it is quiet to operate, free from contamination, and under accurate temperature control. The only maintenance required is an occasional change of elements, which can be done without in any way disturbing the construction of the furnace. The elements are of the silicon carbide type. These furnaces are built in various sizes to take melts of 10–15–30–45–60–75–90 and 110 lb., and larger furnaces can be built as necessary. All are designed to take standard crucibles.



Hedin, Ltd., Commerce Estate, South Woodford, London, E.18.

Taper Jointed Graphite Electrodes

BRITISH ACHESON ELECTRODES, LTD., makers of the well known Acheson graphite electrodes for electric arc furnaces, recently announced the extension of their range of large diameter taper jointed electrodes. The 16 in. and 14 in. diameter Acheson electrodes with taper jointing have now been introduced to join the well established 20 in. taper jointed electrodes. The new 16 in. electrode has a nipple with a major diameter $8\frac{3}{4}$ in. and length 12 in. This means a thicker socket wall all round, in addition to the extra protection and

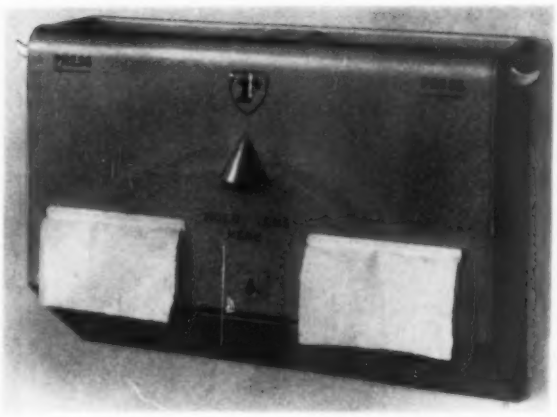
life given to the socket by the 1 in 6 taper. The new 14 in. electrode is machined to take a nipple 8 in. at the major diameter and 10 in. long: this again means a thicker socket wall. For maximum security and tightness of joints, threading of nipple and socket are four threads per inch, machined to fine tolerances to ensure perfect matching of tapers. These new electrodes will shortly be followed by 12 in. electrodes with nipples and sockets for taper joints.

British Acheson Electrodes, Ltd., Wincobank, Sheffield.

Safety Lens Cleaning Equipment

ONE of the chief complaints about industrial eye protection is that it steams or fogs up. Manufacturers are continually seeking to overcome this problem by better design and improved forms of ventilation, but there are circumstances where it cannot be prevented entirely. Fogging, when it does occur, can add to hazard, and always provides an excuse for eye protection not to be worn. Furthermore, lenses get dirty and workers rarely think of cleaning them, but prefer once again to leave the goggles or spectacles lying on the bench rather than to use them.

It is for these reasons that the Fleming lens cleaning and de-misting cabinet No. 0063 has been designed. The liquid, which is dispensed in a fine spray when the lever on either side of the cabinet is depressed, cleanses as it de-mists. As a piece of really clean cloth is usually difficult to obtain in the average factory, tissues are



provided in the cabinet, together with space for their disposal after use. Neither liquid nor tissues will damage plastic materials.

It is estimated that where the Fleming lens cleaning and de-misting cabinet is installed, at least twelve goggles or spectacles can be treated at a cost of one penny, and the operation of cleansing and de-misting takes seconds only. The installation of these cabinets and the proper use of them by workers would, it seems likely, do much to encourage eye protection to be worn regularly.

Fleming Safety Equipment (Division of J. & R. Fleming, Ltd.), 146, Clerkenwell Road, London, E.C.1.

Decksmetal Floor Armour

CAUSEWAY REINFORCEMENT, LTD., manufacturers of Hexmetal steel cellular reinforcement, are now able to supply Decksmetal, a low-priced surface armour for use with mastic asphalt or rubber compound floorings. Decksmetal is manufactured in 4 ft. long strips in such a way that easy and speedy assembly on site is permitted. By means of a special tongue and slot design the strips can be fabricated into a continuous floor armour which fully stabilises the asphalt and provides a tough surface where arduous trucking problems are encountered. The mesh is provided in 14 gauge material, 1 in. deep, and each cell measures 3 in. It is treated with a bitumen compound before despatch to ensure easy adhesion to the asphalt flooring. Where Decksmetal is to be laid on soft underlays, a flat support strip is provided.

Causeway Reinforcement, Ltd., 66 Victoria Street, London, S.W.1.

Vapour Blasting Equipment

A NEW type of vapour blasting equipment, fabricated from Vybak industrial rigid P.V.C. sheet made by Bakelite, Ltd., is now being marketed under the trade name Hydrotron. The Hydrotron is built almost entirely from plastics materials and comprises basically a Vybak blasting cabinet and supporting structure, beneath which is located a large polyethylene container for holding the abrasive slurry. Compressed air is used to displace the slurry from the container to the blasting gun housed in the cabinet. Other design features include a rigid P.V.C. extractor unit with Nylon impellor, built-in rubber sleeves to protect the operator's

hands, and an automatic washing device for the observation window.

A number of important functional advantages are claimed for the Hydrotron. For example, the abrasive within the slurry cannot be contaminated by the rigid P.V.C. used in the construction of the equipment, and abrasives, or grades of slurry, can be altered in a moment merely by changing to another polyethylene container. The speed of the particle is higher than with any other known equipment, and the slurry feed system and working cabinet can be quickly and easily washed down when changing from one metal or slurry to another.

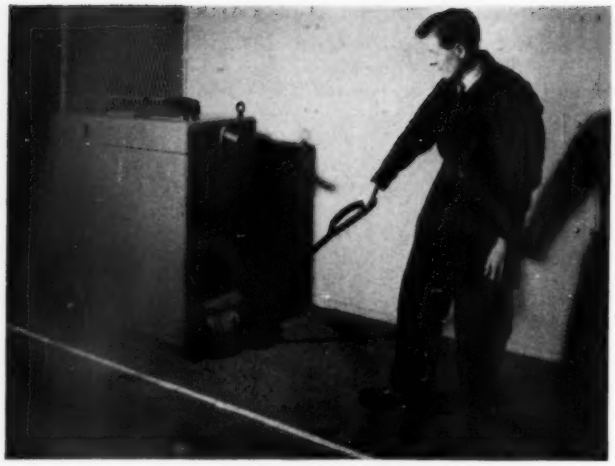
Almost every cleaning or etching technique can be replaced by this new method, and all metals that are in any way capable of being plated can be prepared by Hydrotron blasting. The equipment is regarded by its designers as essential for depositions on molybdenum, uranium, titanium or magnesium alloys.

Metachemical Processes, Ltd., Crawley, Sussex.

Wheel-Mounted Welding Set

CLAIMED to be the largest single-operator wheel-mounted A.C. welding set at present available, a unit providing a maximum intermittent welding current output of 700 A. at 80 V. has been introduced by The General Electric Co., Ltd. This set, designated the O.T.2, has a welding current output from 120 to 700 A. in 25 steps, with a continuous manual welding current rating of 650 A. Rated at 52 kVA., in accordance with B.S.638 group Y, it consists of an oil-immersed single-phase transformer and separate choke enclosed in a fabricated sheet-steel tank which can also contain a 20 kVAr. air-cooled capacitor inside a separate compartment.

Regulating handles for coarse and fine current adjustments control the welding current. Primary transformer tappings are brought to a terminal board immediately beneath a small lid on the top cover, and provide for a primary voltage range from 380 to 550 V.



in six steps. Full instructions for making the correct primary transformer connections and for obtaining the required welding current are given on prominent diagram plates mounted on the top cover.

The components and windings are securely braced to prevent any possibility of movement, even under the rough handling which gear of this type is likely to receive in service. The whole unit is mounted on four rubber-tyred wheels.

The General Electric Co., Ltd., Magnet House, Kingsway, London, W.C.2.

Automatic Die Production

NEW programming methods, evolved by engineers at E.M.I. Electronics, Ltd.'s Hayes laboratories, now make it possible to produce first-class dies on milling machines, direct from the drawing, without the use of an external computer. Special mathematical techniques were devised to provide continuity in 'blending' between the co-ordinates shown on the normal blueprint and produce fully three-dimensional work pieces. As in the other E.M.I. control systems, punched tape feeds instructions into what is in effect a built-in computer which controls the mill.

This system gives several outstanding advantages over the conventional method of die-sinking from mahogany or metal models. For a typical medium-sized product, the tape can be programmed in about half the time required to make a wooden prototype. As girl programmers can be employed instead of skilled model-makers, the cost per hour is also greatly reduced. It is found in practice that the machining time, too, is considerably less than by normal methods. The new system ensures a consistent accuracy of $\pm 0{\cdot}002$ in.—much greater than could be achieved by the use of wooden models.

Forging, casting and plastic moulding dies can all be produced on machines equipped with the E.M.I. system. Turbine blades, car rear lights and telephones are just three examples of the type of articles for which dies can be produced more efficiently. Furthermore, an electronically controlled vertical milling machine costs very little more than a conventional copying die-sinker of the same size.

E.M.I. Electronics, Ltd., Hayes, Middlesex.

CURRENT LITERATURE

Book Notice

SURFACE DEFECTS IN INGOTS AND THEIR PRODUCTS

Second edition. Iron and Steel Institute Special Report No. 63. 62 qto. pp., 134 photographs of surface defects, cloth bound with stiff board covers. 25s. (Members of the Institute, 15s.)

DURING an investigation into the causes of ingot surface defects and their influence on the product, the Ingot Surface Defects Sub-committee of the British Iron and Steel Research Association became aware that there was a lack of uniformity in the names applied to the defects under review. To reduce the confusion of terms and promote a better understanding of the nature and causes of such defects, the Sub-committee selected those most commonly encountered and assigned to them the most apt term.

The first edition of this survey appeared in 1951 as No. 44 in The Iron and Steel Institute's Special Report Series, and was quickly sold out. In view of the many requests for copies of what is now a standard work of reference, it was decided to issue a second edition, with some important additional material. Through the courtesy of Richard Thomas and Baldwins, Ltd., The Steel Company of Wales, Ltd., and John Summers and and Sons, Ltd., the Sub-committee has been able to include an addendum devoted to surface defects in sheet products.

CLASSIFIED RADIOGRAPHS FOR DEFECTS IN ALUMINIUM FUSION WELDS

Booklet H3/58, published by the British Welding Research Association, 29 Park Crescent, London, W.1. 52 pp., 53 illustrations. 10s.

INSPECTORS, welding engineers, designers and fabricators of aluminium alloys will be interested in this new booklet, which shows how to identify those defects in aluminium fusion welds which can be seen in radiographs. The defects are classified, their origin explained and suggestions for their prevention are made. The booklet has been prepared by the senior metallurgists of B.W.R.A. helped by a panel of experts from industry.

Many more defects can exist in aluminium alloys than in mild steel, mainly because they can be fabricated by several different processes. The devising of a logical system for classifying these defects is, therefore, a step forward. The book recognizes five groups of defects:

(1) Cracks.
(2) Lack of fusion, including incomplete root penetration.
(3) Voids, including the three types of porosity,—uniform, localised and linear—as well as elongated cavities and crater pipes.
(4) Inclusions of oxide, flux or metal—the latter usually tungsten but sometimes copper or iron.
(5) Imperfect shape, including defects which may, or may not, be seen on visual inspection, depending on the joint design, such as undercut, excessive penetration and root shrinkage.

Surface marks give characteristic shadows in radiographs, and they are therefore included though they are not defects.

General indications are given of the ways in which the defects influence joint properties, but except for uniform porosity this is only qualitative. A simple system is given for recording the severity of uniform porosity and its probable effect on joint efficiency. No attempt has been made to indicate acceptance standards, although the booklet may well form a useful basis for discussions on such standards.

The booklet is well indexed for easy reference and the cost is very reasonable in view of the experience which it summarizes and the savings which can result from its use. The radiographs in the book were chosen out of several hundred provided by the co-operating companies.

KEMPE'S ENGINEERS YEAR BOOK 1959

64th edition. Morgan Brothers (Publishers) Ltd., London. In two volumes: Vol. I 1324 pp., Vol II 1416 pp., numerous tables and diagrams. 82s. 6d.

KEMPE'S ENGINEERS YEAR BOOK is one of the most widely known reference books in this country and there must be few engineers who have not, at one time or another, referred to Kempe's for information on a part of the subject which may be unfamiliar to them.

The 64th edition follows the same pattern as previous editions; all branches of engineering are covered and the various sections of each branch are dealt with by authors who are specialists in that particular field. The sections contain the more common formulae in current use, and an account of the present practice or trends in industry. A list of references to published work on the subject is also given. Many of the sections have been revised and re-written to bring the subject up to date. The great strides made in recent years in aeronautics, nuclear engineering and material handling, to mention just a few examples, are recorded, and, to quote a topical issue, the fundamental equations dealing with motion of missiles, motion of satellites and escape velocities are included.

Kempe's remains what it always has been—an excellent up-to-date reference book, particularly suitable for those engineers whose duties range widely over a number of branches of engineering.

Trade Publications

A DETAILED brochure covering the design and production of heavy press aluminium extrusions has been prepared by Harvey Aluminum, 19200, S. Western Avenue, Torrance, California. Featured in the 16 page publication is a review devoted to designing for heavy press extrusions, including the types of sections which can be produced and standard manufacturing limits for solid shapes, hollow shapes, panels, and tube. To demonstrate the versatility of big extrusions, applications now being designed with large aluminium shapes are structural components for transportation equipment, missile and airframe sections, structurals for bridges, bus bar for electrical distribution systems, atomic energy tubes, architectural and building shapes, and cooling panels for aircraft carrier decks.

ALTHOUGH manufacture began only five years ago on a very modest scale at Dudley, the Control Gear Division

of G.W.B. Furnaces, Ltd., has already established a high reputation among a growing number of customers. The Division has expanded considerably at Dudley, and a new works has been built at Bangor in Northern Ireland. During this period of consolidation, G.W.B. have had the benefit of access to the designs of Officine Meccaniche Riunite of Milan, but the Division has its own design, development and drawing offices. A new illustrated brochure features the manufacturing facilities at Dudley and Bangor, together with typical installations in the steel, gas, rubber, paper, and other industries.

THE wide range covered by the literature summarised in the February issue of *The Nickel Bulletin* is indicative of the growing importance of nickel in almost every branch of industry. The many fields specifically dealt with in articles in this issue include: magnetic materials; chill-cast rolls; fatigue strength of nickel-containing steels; steels for use in the blades of the Rotodyne vertical-take-off aircraft; nickel plating (patterned coatings); and heat- and corrosion-resisting alloys and steels.

ONE of the first companies to undertake the forging of titanium when the metal was first produced on a commercial scale in this country, Daniel Doncaster and Sons, Ltd., of Sheffield, are now successfully forging on a production basis such metals as titanium, Nimonic, zirconium, aluminium bronze, heat resisting alloys, high permeability iron, etc. To assist firms in industries now considering the application of the newer metals in their own particular products, Doncasters have issued a well-illustrated brochure entitled "The Advanced Manipulation of Difficult Raw Materials." Reference is made to the versatile combination of plant, equipment and experience in this field which is available within the company, one section being concerned with the production of precision forged blades for compressors and turbines. The booklet also includes mention of powder metallurgy, and the production of hardened forged steel rolls for cold rolling.

A NEW publication has been issued describing the properties and uses of the various grades of nickel-chromium and nickel-chromium-iron alloys manufactured by Henry Wiggin & Co., Ltd. Known as the Brightray series of alloys, these materials include electrical resistance alloys for use up to a maximum operating temperature of 1,250° C., covering the requirements of practically all domestic and industrial heating applications. In addition to giving concise data on these alloys, the publication includes sections on materials for leads and connections, furnace elements, thermocouples, etc., and forms a useful guide to the selection of the correct grade of material to meet specific conditions.

SINCE Northern Aluminium Co., Ltd., first issued its book "Welding Aluminium" some 3½ years ago, great advances have been made in this field. An extensively revised edition of the book has now been produced, which deals almost exclusively with the two shrouded arc processes—argon-tungsten-arc and inert-metal-arc. The information on processes has been brought up to date, a section has been added on welding technique, and the tables of procedures—still the most useful part of the book—have been entirely revised, with full explanatory notes and illustrations giving edge preparation and joint details. In addition an appendix has been added giving information on alloys and current ratings.

E.M.I. ELECTRONICS, LTD., has just produced a new folder to introduce the company's closed-circuit television equipment which has proved so successful in various fields of industry. Various applications are described, ranging from visual control of several widely-separated operations; observation of dangerous processes; training and surveillance; to such uses as sales conferences; demonstrations in department stores; and the transmission of blueprints, signatures and other data.

WE have received from the Cambridge Instrument Co., Ltd., two new publications. The first of these, List 28, describes a new centre-line indicator-controller incorporating a novel display of the "desired" and "measured" values. When the pointer lines up with a fixed datum on the centre line of the scale, the plant is "on control," and any change in this condition is immediately visible, even from distances at which scale graduations cannot be read. It is available in either on-off or time-modulated three-term control. List 144/A, "Gas Analysers—General Principles," deals with some of the technical problems associated with gas analysis by the thermal conductivity method. It gives performance data on the Cambridge Katharometer, and includes notes on the types of measurement available, and on the possible sources of error.

WE have received from Climax Molybdenum Company a new booklet entitled "The Role of Molybdenum in Abrasion-Resistant Materials," based on the company's experience and investigations, which have led to the development of four materials for service in this field. Following a general picture of the different types of abrasion, a more detailed consideration is presented of the behaviour of these materials under conditions typical of certain types of abrasion. Finally, guidance is given on the production and treatment of the four materials—the chromium-molybdenum steels; a 12% Mn, 2% Mo steel; a 15% Cr, 3% Mo iron; and a 3% Ni, 2% Cr, 1% Mo iron.

Books Received

"Introduction to the Theoretical and Experimental Analysis of Stress and Strain." By A. J. Durelli, E. A. Phillips and C. H. Tsao. 498 pp. inc. index. New York, Toronto and London, 1958. McGraw-Hill Publishing Co., Ltd. 97s.

"Growth and Perfection of Crystals." Edited by R. H. Doremus, B. W. Roberts and D. Turnbull. Proceedings of an International Conference on Crystal Growth held at Cooperstown, New York, August 27th–29th, 1958. 609 pp. inc. author and subject indexes. New York and London, 1958. John Wiley & Sons, Inc., and Chapman & Hall, Ltd. 100s. net.

"Advances in Inspection Techniques as Aids to Process Control in Non-Ferrous Metals Production." A Symposium held in London on May 1st, 1958. 103 pp. London, 1958. Institute of Metals. 30s. or $4.65.

"Constitutional Diagrams of Uranium and Thorium Alloys." By F. A. Rough and A. A. Bauer. 153 pp. Massachusetts, 1959. Addison-Wesley Publishing Company, Inc. $5.00.

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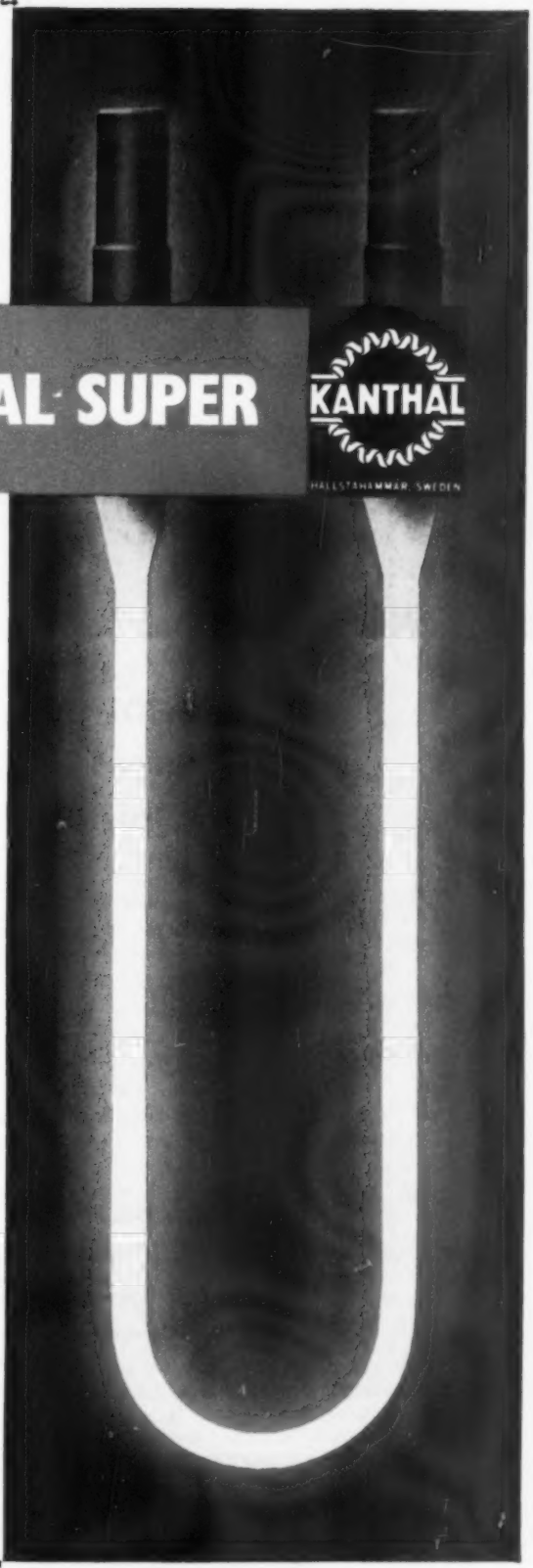

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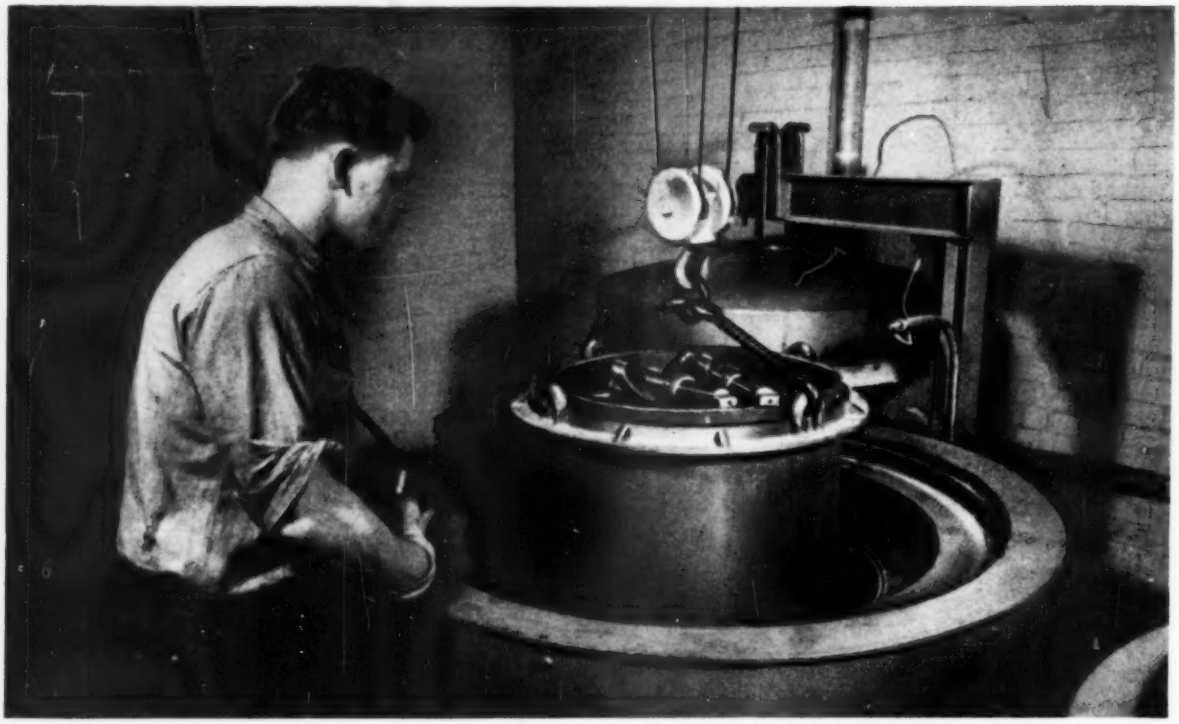

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APRIL, 1959 Vol. LIX, No. 354

The Ring Balance Differential Pressure Meter

By T. C. Toye, B.Sc., A.Inst.P.

Lecturer in Industrial Instrumentation at Swansea Technical College

The ring balance differential pressure meter is widely used in the measurement of flow. The author sets out the basic theory of the instrument, and discusses the errors involved when the incorrect quantity or type of sealing liquid is used.

THE ring balance differential pressure meter is probably the least understood of all industrial instruments. This is very largely due to the fact that text books vary considerably in the method of treatment used, and in some cases are incorrect. This naturally leads to confusion among students and users alike, and is certainly not conducive to an intelligent use of the instrument, nor to a proper appreciation of its limitations. This article has therefore been written in an attempt at a clear and simple description of the basic theory, together with a statement of the direction of the errors involved when the incorrect quantity or type of sealing liquid is used.

The ring balance, a sectional drawing of which is shown in the diagram, is essentially a U-tube shaped in the form of a doughnut ring, in which the ends of the limbs are separated by a partition B. The differential pressure is applied via flexible pipes to the inlet points X and Y. The ring is partly filled with manometer liquid and the whole instrument pivoted on a knife edge at O. A control weight W is attached to the ring as shown, provision being made so that it can be interchanged with weights of various values for different ranges. The partition C contains an aperture and serves to damp the motion of the ring. When a differential pressure is applied to X and Y, then inside the ring the usual manometer effect takes place, i.e., the liquid is displaced until a differential head equal to the applied differential pressure is formed, thus, for $P_1 > P_2$

$$P_1 - P_2 = \rho h$$

where ρ is the density of the liquid. When this state has been reached the liquid inside the ring will be in equilibrium with the applied pressures, but for the ring as a whole this is not the case.

As well as acting on the surfaces of the liquid, the pressures P_1 and P_2 act on the inside walls of the ring above the liquid, and the geometry is such that the resultant forces on either side of the partition B act in opposition, and therefore produce a turning moment on the ring about the pivot O. This moment will be clockwise when $P_1 > P_2$ in the case discussed. The control weight W serves to produce an anticlockwise, or restoring moment of

$$Wd \sin \theta$$

where θ is the angular deflection of the ring. Taking moments about O, then for equilibrium

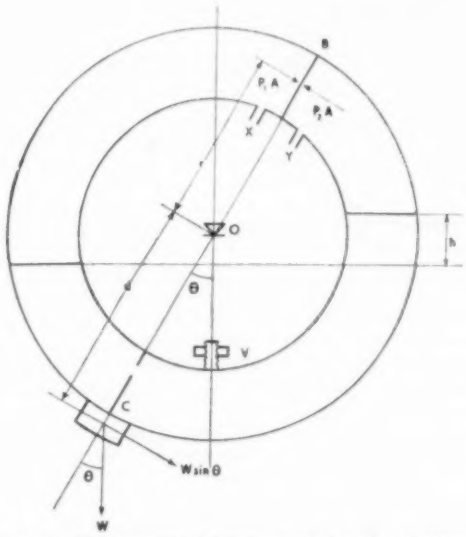


Fig. 1 The essential features of the ring balance differential pressure meter.

$$\text{Clockwise moments} = \text{Anticlockwise moments}$$
$$Ar\,(P_1 - P_2) = Wd \sin \theta$$
$$\text{Whence } P_1 - P_2 = \frac{Wd \sin \theta}{Ar}$$

and since W, d, A and r are constants, measurement of the angular rotation θ gives a measure of $P_1 - P_2$.

The maximum differential pressure is given by $\theta = 90°$

$$\text{i.e. } (P_1 - P_2)_{max.} = \frac{Wd \sin 90°}{Ar} = \frac{Wd}{Ar}$$

and W can be calculated to suit the maximum value of differential pressure it is required to measure.

The important fact in the above derivation is that the only moments involved are : that due to the differential pressure on the partition B; and that due to the component of the control weight W. For this to be permissible when moments are taken about O, then obviously there must be no other moment about that point. This can

only be the case if the centre of mass of the whole instrument is located at *O*, with *W* removed, of course. Thus the quantity and density of the liquid is important, because variations from the manufacturers' specifications will result in a displacement of the centre of mass away from *O*, and false readings will result. On some instruments a knurled adjusting weight *V* can be raised or lowered until the centre of mass is located accurately at *O*. This adjustment is made with *W* removed, and with the rubber tubes disconnected from *X* and *Y*, by positioning *V* so that the ring will remain at rest when placed in any position : this can only happen when the centre of mass is at *O*.

The direction of the errors involved when incorrect quantity and/or type of liquid is used are set out below.

(1) *Liquid Density Correct*

(*a*) *Quantity Insufficient.*—The centre of mass is raised, and when the ring is rotated as shown the mass exerts an assisting moment and the reading is too high.

(*b*) *Quantity Excessive.*—The effect is variable, but the centre of mass is usually lowered and the reading is too low.

(2) *Liquid Quantity Correct*

(*a*) *Density too High*—The centre of mass is lowered and the reading is too low.

(*b*) *Density too Low*—The centre of mass is raised and the reading is too high.

From the foregoing it can be seen that combinations of inaccuracies regarding the type and quantity of the filling liquid will cause greater or lesser errors in the appropriate direction.

The value of differential pressure is, in the majority of cases, needed only as a measure of flow. The use of square root correcting devices does not, however, affect the comments made here.

Metallographic Differentiation of Cobalt Metal, Oxide and Sulphide

By R. S. Young, Ph.D., F.R.I.C., F.I.M., M.I.Chem.E.

Etching in 1% mercuric chloride for 30 seconds or in 35% sodium bisulphite for two minutes is recommended as a means of distinguishing microscopically between cobalt metal, cobalt oxide and cobalt sulphide.

IN both the extractive and fabricating fields of cobalt metallurgy, to supplement information derived from chemical analyses, an examination of powder compacts or polished sections is occasionally required to determine the presence of metallic, oxide and sulphide forms of the element. It is not easy, even for an experienced microscopist, to differentiate the phases in an unetched briquetted sample of powdered cobalt metal, oxide and sulphide obtained from various stages in extractive and refining processes. The sulphide has a smooth, yellowish white appearance, whereas metallic cobalt is whiter but less smooth. Cobalt oxide is dark grey, and, since it does not polish quite as readily by conventional techniques as the sulphide or metal, it is rougher than the latter.

The procedures described by Hall[1] for the differentiation of sulphides in nickel did not give satisfactory results with cobalt, with the exception of 2% nital. Etching with the latter for 30 seconds produces a faint brown stain on metallic cobalt, whereas the sulphide is unaffected. Cobalt oxide is likewise virtually unaffected, but is distinguished by its original darker colour from the sulphide.

Examination of commercial cobalt metal in the unetched state reveals the metallic phase as large white or light grey grains, with cobalt sulphide occurring as a yellowish phase along the grain boundaries. Manganese, frequently present in commercial cobalt where it prevents embrittlement by sulphur when this element exceeds about 0·01%[2], appears as bluish grey manganese sulphide.

Etching with 1% mercuric chloride for 30 seconds imparts a dark brown colour to metallic cobalt, but is without effect on the sulphides and oxides of cobalt, and on manganese sulphide. When 5% nital for 30 seconds is used as etchant, a light brown stain appears on the metallic portion ; cobalt sulphide is unaffected, but attack occurs on manganese sulphide. One of the best etchants for most samples is 35% sodium bisulphite, which in two minutes stains the metallic phase brown, but is without effect on cobalt sulphide, cobalt oxide, and manganese sulphide.

Cobalt metal, oxide and sulphide can thus be distinguished microscopically by prior etching of the sample with 1% mercuric chloride for 30 seconds, or 35% sodium bisulphite for two minutes. Both reagents impart a brown stain to the metallic phase but leave unchanged the dark grey oxide and the yellowish white sulphide. Manganese sulphide, if present, remains unaltered as a bluish grey constituent.

REFERENCES

1 Hall, A. M., Sulphides in Nickel and Nickel Alloys, *A.I.M.E. Trans.*, **152**, 278–85 (1943).

2 Martin, D. L., Sulphur Embrittlement of Cobalt, *J. Metals*, **8**, 578–9 (1956).

Griffin & George Research Company

A NEW company, Griffin & George (Research and Development), Ltd., has been formed by the Griffin & George Group to conduct research into and the development of, new and improved scientific instruments and apparatus for laboratory use and process control. The Research Director is Dr. A. J. P. Martin, F.R.S., well-known for his work on partition chromatography, acknowledged by the award in 1952 of the Nobel Prize for chemistry (jointly with Dr. R. Synge).

New laboratories to house the research and development staff will be designed and equipped. A major part of the Company's effort will be directed towards a review of modern analytical techniques and the development of the instruments and apparatus for applying them in the laboratory and on the plant. At the same time, work will be conducted on modernising and extending the Group's range of apparatus for use in educational laboratories.

Exhibits of Metallurgical Interest at the Physical Society's Exhibition

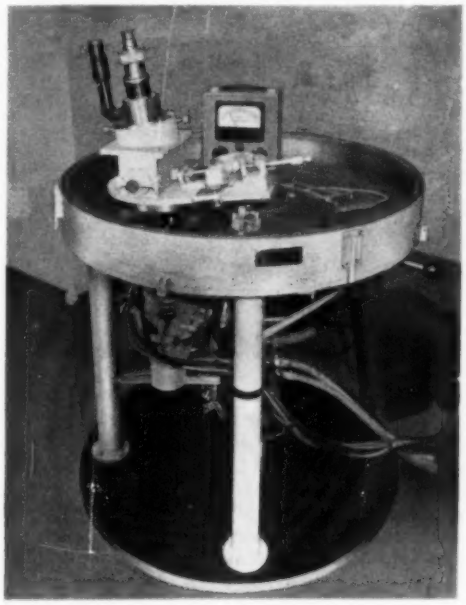
The exhibits at the Physical Society's annual exhibition of scientific instruments usually include a number of interest to workers in the metallurgical field. This year was no exception, and in this issue we continue a short series of reviews in which such items will be described.

X-Ray Microanalyser

THE X-ray microanalyser shown by Metropolitan-Vickers Electrical Co., Ltd., was developed by the Associated Electrical Industries Research Laboratory at Aldermaston, and is the prototype of production models at present being constructed by Metropolitan-Vickers. It enables quantitative chemical analyses to be performed with small volumes (about 1 cubic micron) of material, using a technique developed in France by Castaing.

A fine electron probe irradiates a minute portion of the specimen and the resulting X-radiation is examined using a crystal spectrometer. The characteristic radiations of an element indicate its presence in the specimen, and the intensity of radiation is an indication of the abundance of the element. A quantitative analysis is carried out by the use of a radiation counter and recorder. Elements ranging from uranium to titanium are readily detected, but compounds containing the lighter elements may be analysed by the use of a proportional counter and a pulse height analyser, which are incorporated in the equipment.

The equipment comprises three main items. First, the console which incorporates the electron probe, spectrometer, optical microscope, and vacuum equipment; secondly, high voltage supplies and electron lens supplies cubicles; and finally, a recording cubicle. The accelerating voltage of the electron gun, from which the probe is derived, can be varied in steps from 10 kV. to 50 kV. and is stabilised to about 1 part in 10,000. Electromagnetic lenses focus the beam into a fine probe of about 250 milli-microns diameter. The spectrometer uses a bent crystal, normally lithium fluoride, and also incorporates an automatically positioned lead screen which prevents direct entry of X-radiation into the Geiger-Muller tubes when operating at low Bragg angles. The recording equipment consists of a combined scaler and ratemeter; the scaler is used for preliminary adjustments and analyses, while the ratemeter is used for more accurate work. A continuous record of the distribution of an element in the specimen is displayed on a strip chart recorder driven by the ratemeter while the specimen is scanned mechanically.



Courtesy of Metropolitan-Vickers Electrical Co., Ltd.

The X-ray microanalyser

The normal high grade × 700 or × 800 metallurgical microscope fitted with a wide angle eyepiece is used to view the specimen and select the micro area for analysis. When this area is central in the field of view, the whole specimen stage is rotated through 180° and the desired area automatically located under the electron probe: no further adjustments to the specimen are necessary. The specimen stage is constructed to hold six specimens, which can be as large as 0·5 cu. in. or secured in ½ in. mounts. Specimen shape is not important, but the surface must be polished as for normal metallurgical work.

Automatic Photographic Enlarger

In the new electronic photographic enlarger—developed by the Graphic Arts Division of E.M.I. Electronics, Ltd. the conventional methods of 'dodging', or shading, certain portions of the negative by hand to obtain correct exposures, have been replaced by a fool-proof electronic system. The new enlarger uses a scanning light beam from a cathode ray tube to obtain automatic shading and exposure control. When the exposing spot of light from the cathode ray tube encounters a dense region on the negative it instantaneously becomes brighter. Conversely, brightness of the spot is reduced for thin regions of the negative, thus producing maximum print detail in both highlights and shadows. A special light integrating system terminates the exposure automatically to produce a uniform print density without adjustment for widely varying negative densities.

E.M.I. have for some time been marketing a Log-Etronic contact printer, which is widely used in aerial survey, medical and other fields. The development of the enlarger enables a far greater variety of work to be undertaken. Science and industry will benefit from its use because by effectively matching the negative density range to the exposure scale of printing paper it is able

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Adjusting the automatic electronic photographic enlarger.

to produce amazing clarification of detail. Furthermore, automatic control means increased production without the necessity of increasing dark room staff. The electronic enlarger is capable of printing from 35 mm. to half plate size negatives, and provides a maximum print area of 30 × 40 in.

Vibratory Polisher

The vibratory polisher, shown in prototype form on the Nash and Thompson stand, has been developed to aid the rapid preparation of large numbers of metallographic specimens with the minimum use of skilled or semi-skilled labour. The principle employed is to place the specimens in a rapidly vibrating tray, in which they are abraded with diamond dust. Twelve or more specimens of varying sizes may be prepared simultaneously, making the polisher of great value to metallurgical control laboratories.

Large specimens need not be mounted, but small ones should be mounted in Bakelite. After preliminary grinding and abrasion down to 1 0 emery paper, the specimens are placed in the tray of the vibrator, which, in the production version, will be about 12–13 in. diameter. It is prepared for polishing by mounting a specially woven Nylon cloth on a $\frac{1}{4}$ in. glass plate, and impregnating with 6 micron size diamond dust paste : the glass plate is rigidly fixed in the tray. With the production version there will be provision for rapidly changing the cloth. A plastic lid will be provided to avoid extraneous contamination of the diamond dust while polishing, and it is suggested that users have several different trays (and lids) for different abrasives, and also for use on different metals if required.

The time of polishing is approximately one hour on the present model, depending on the state of the cloth and the abrasive, and the metal being polished. It is believed that improvements in the vibratory technique, in the Mk II being developed, will considerably shorten this period. All scratches are removed in this time and the specimen is ready for finishing on 1 micron diamond dust if so desired. A certain amount of relief polishing is encountered if the specimen is below about 750 g. in weight, and special lead collars are provided to load small specimens. Really large specimens (say sections up to 4–5 in. diameter), can be polished (without loading) in company with the smaller loaded specimens : the mixture of large and small specimens does not adversely affect the polishing.

Non-Magnetic Tube Tester

The tube tester shown on the stand of C.N.S. Instruments, Ltd., is designed for the rapid location of faults in tubes of non-ferrous metal or austenitic stainless steel, and for locating corrosion of steam condenser tubes. The instrument shows up cracks, inclusions, superficial faults, local changes in wall thickness, and corrosion, and once the initial setting has been made, testing can be carried out by untrained personnel.

The equipment consists of probes containing search coils which are passed around or through the tube specimen. The proximity of the metal occasions certain resistive and inductive changes in the coil characteristics, which remain constant as long as the tube metal is consistently homogeneous and fault-free. The coils are balanced to give zero reading on a piece of good tube, and faults are indicated by meter reading, warning light, and buzzer alarm. With a high speed alarm, relay testing can proceed at 100 ft./min. In practice it has been found that cracks amounting to 5% of the wall thickness are easily detectable, and a $2\frac{1}{2}$% step in wall thickness gives a pronounced signal. It is possible to adjust the sensitivity so as to ignore minor faults.

Courtesy of C.N.S. Instruments, Ltd.

The C.N.S. tester for non-magnetic tubes.

Different materials have different resistivity and permeability values and for this reason it is necessary for the equipment to be capable of operating on various frequencies, so that the maximum penetration and sensitivity can be achieved. To this end the instrument has a frequency switch giving four ranges which are sufficient to cover all materials in normal use. Tubes with exceptional wall thicknesses may also need a changed frequency to achieve full penetration, and where the material is particularly thick-walled and of low resistivity and permeability, then probing is desirable from both inside and outside the tube.

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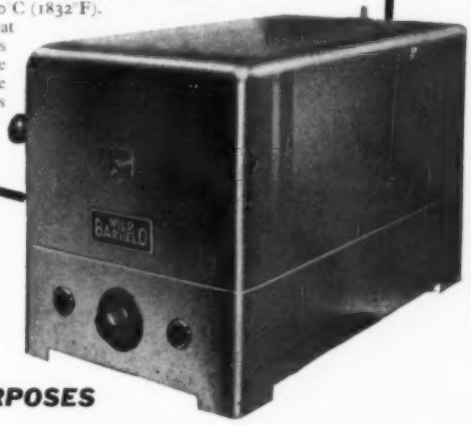

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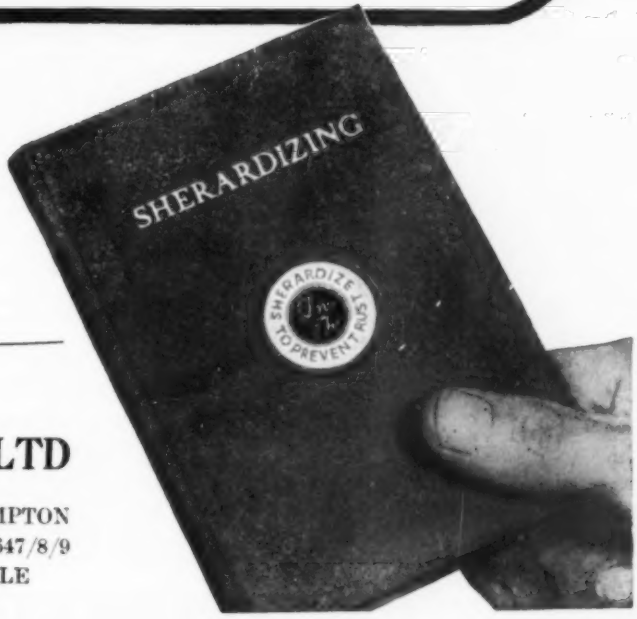

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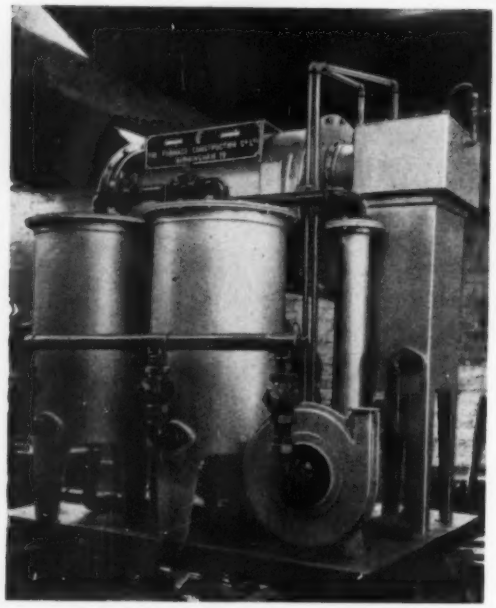

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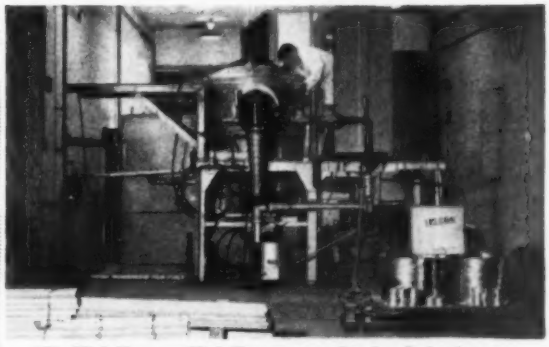

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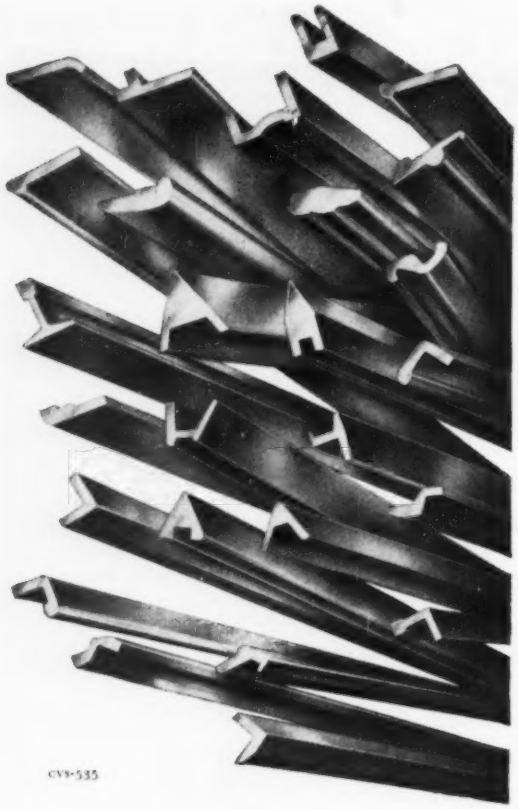

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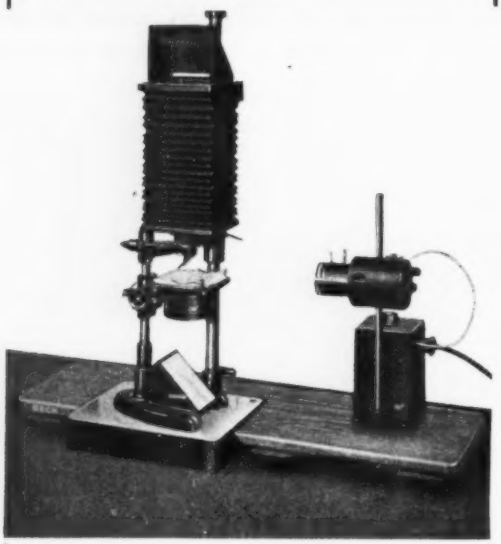

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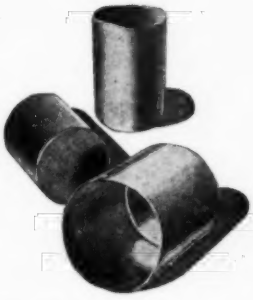

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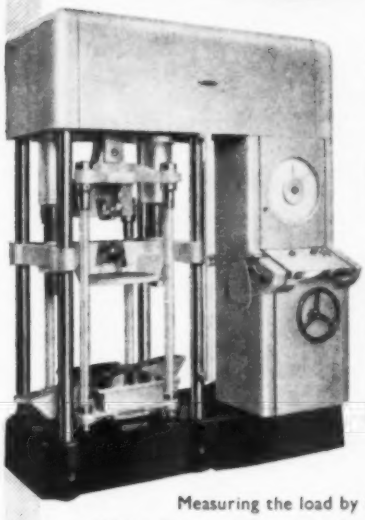

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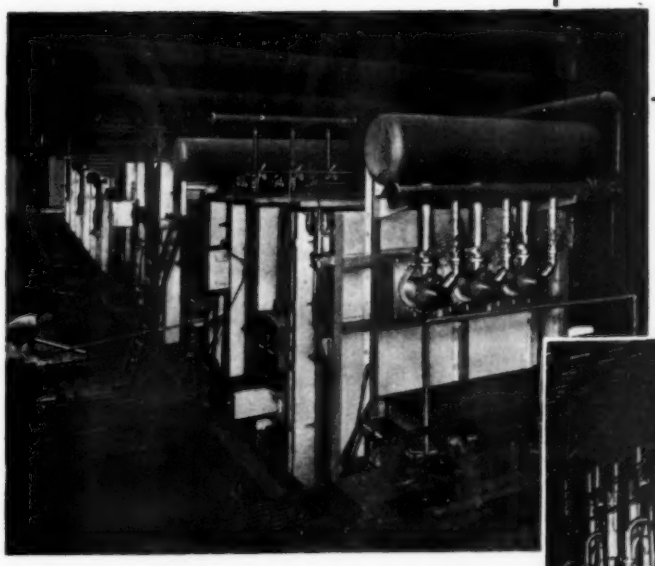

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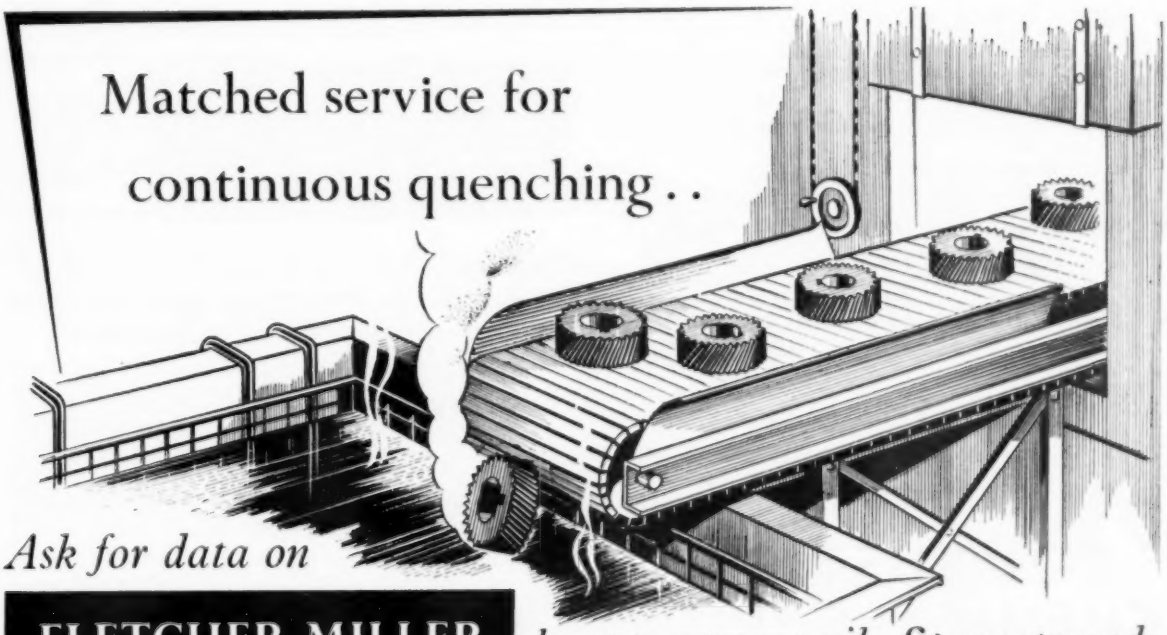

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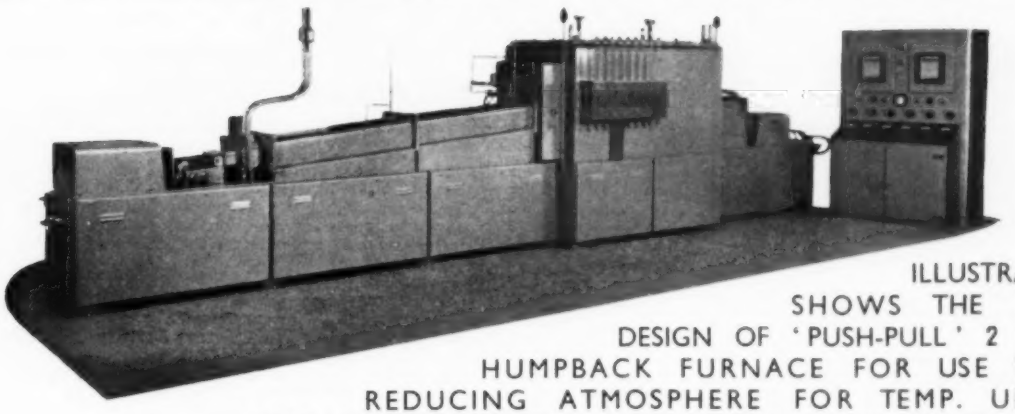

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An opening is available in London Office of International Oil Company for a B.Sc. Metallurgist or Mechanical Engineer to study and solve corrosion problems encountered in the producing, refining and marketing of oil and oil products and to provide technical assistance in the development of materials and protection devices.

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BRITISH WELDING RESEARCH ASSOCIATION require a Research Officer and an Experimental Officer in the non-ferrous section of the Metallurgy Department at ABINGTON HALL, near CAMBRIDGE. Initially, work will be on problems in the inert gas shielded welding of aluminium alloys. The Research Officer, who should be a graduate in metallurgy, or A.I.M., will be required to plan and carry out programmes and prepare reports under the direction of the head of the section. The Experimental Officer will collaborate with the Research Officer on practical aspects of the work and for this purpose, experience of inert gas shielded welding processes is essential. Salary in range: £650–£1,150. Superannuation scheme (F.S.S.U. for graduate or professionally qualified officers). Removal expenses paid. Applications to the Secretary, B.W.R.A., 29, Park Crescent, London, W.1.

MINISTRY OF SUPPLY require Industrial Radiologist at Harefield, Middlesex. Duties involve (a) Practical radiography of welds, castings and assemblies using X-ray sets generating up to 1,000 kV; also gamma-ray sources, (b) Work directed towards new applications of radiographic inspection, (c) Assessment of drawings and radiographic techniques for aircraft and guided weapon castings and welded parts, (d) Assistance in lecturing at training courses. *Qualifications*: Recognised engineering apprenticeship or equiv., training in appropriate trade. Considerable experience essential in radiography of welds and castings, evaluation of radiographic evidence, and development of techniques. Knowledge of welding and foundry practice an advantage. Possession of H.N.C. in Applied Physics desirable and City and Guilds Cert. in Industrial Radiography an added advantage. Salary: £1,030–£1,250 p.a. Forms from M.L.N.S., Technical and Scientific Register (K), 26, King Street, London, S.W.1, quoting A.88/9A. Closing date, 17th April, 1959.

SCIENTISTS and EXPERIMENTALISTS

are required at the Atomic Energy Research Establishment, HARWELL to join a team engaged in research into radiation damage in fissile materials and steels, involving the development of experimental techniques for irradiating samples in nuclear reactors, the examination of radioactive specimens and the interpretation of results. For Scientific Officer posts, a university honours degree required; for the Experimental posts, H.N.C., good G.C.E. "A" levels or equivalent required. Experience in the metallurgical field would be useful. Salaries depending on age, qualifications and experience: Scientific Officer, £675–£1,160; Experimental class £500 (at age 20)–£1,260.

Please send a POST CARD to the Group Recruitment Officer (1374/126), U.K.A.E.A., A.E.R.E., Harwell, Berks, for details.

MISCELLANEOUS

WANTED: one copy of the September, 1958, issue of the Journal, METALLURGIA. The Steel Company of Canada, General Offices, Hamilton, Canada.

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The Governors invite applications for following posts in Department of Mechanical Engineering, to commence 1st September, 1959. Posts additional to present establishments as result of continued expansion of work of College, which is being developed to meet full requirements as an Advanced College. Duties mainly with Sandwich Diploma Courses:—

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(c) CHEMIST, with Higher National Certificate, for work on corrosion and protection problems. Some knowledge of paints and plastics would be an advantage.

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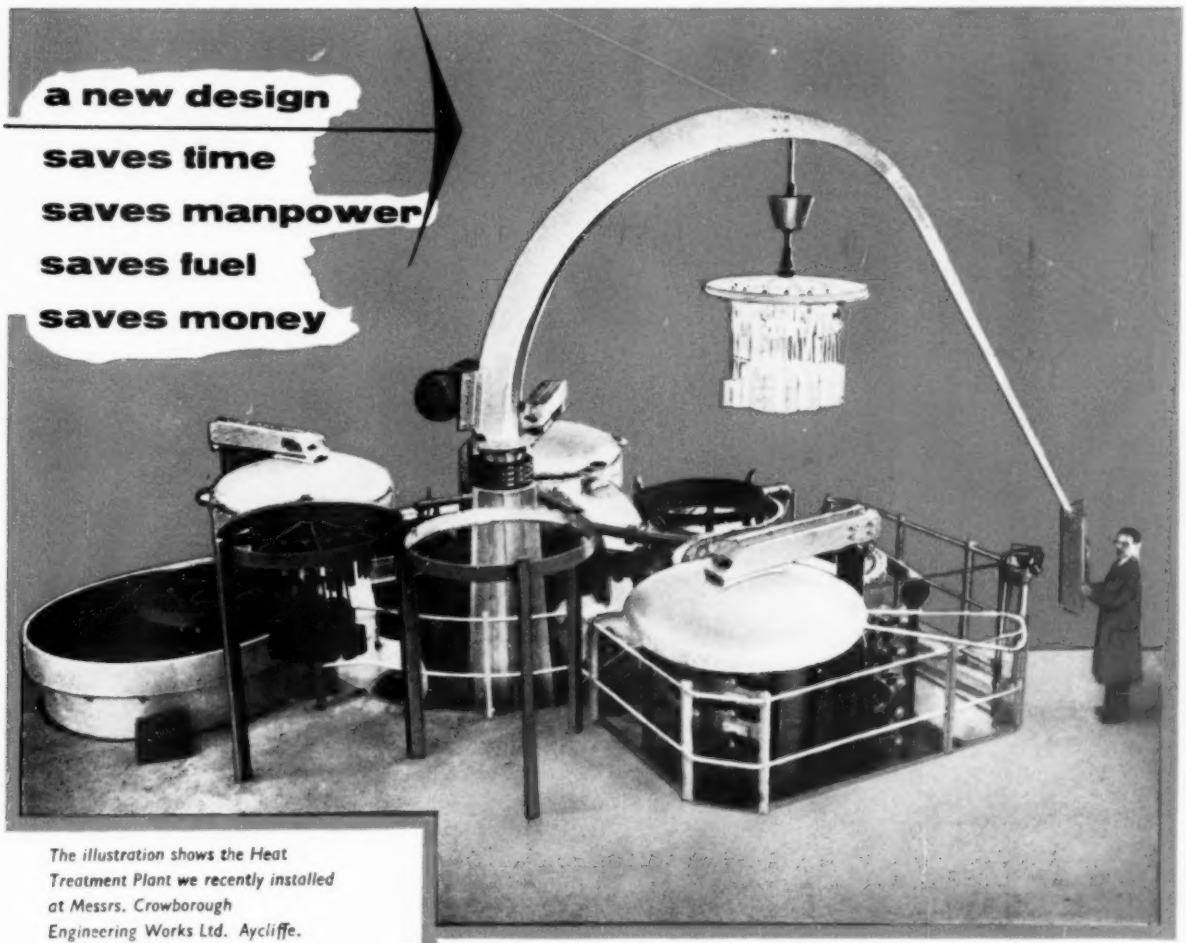

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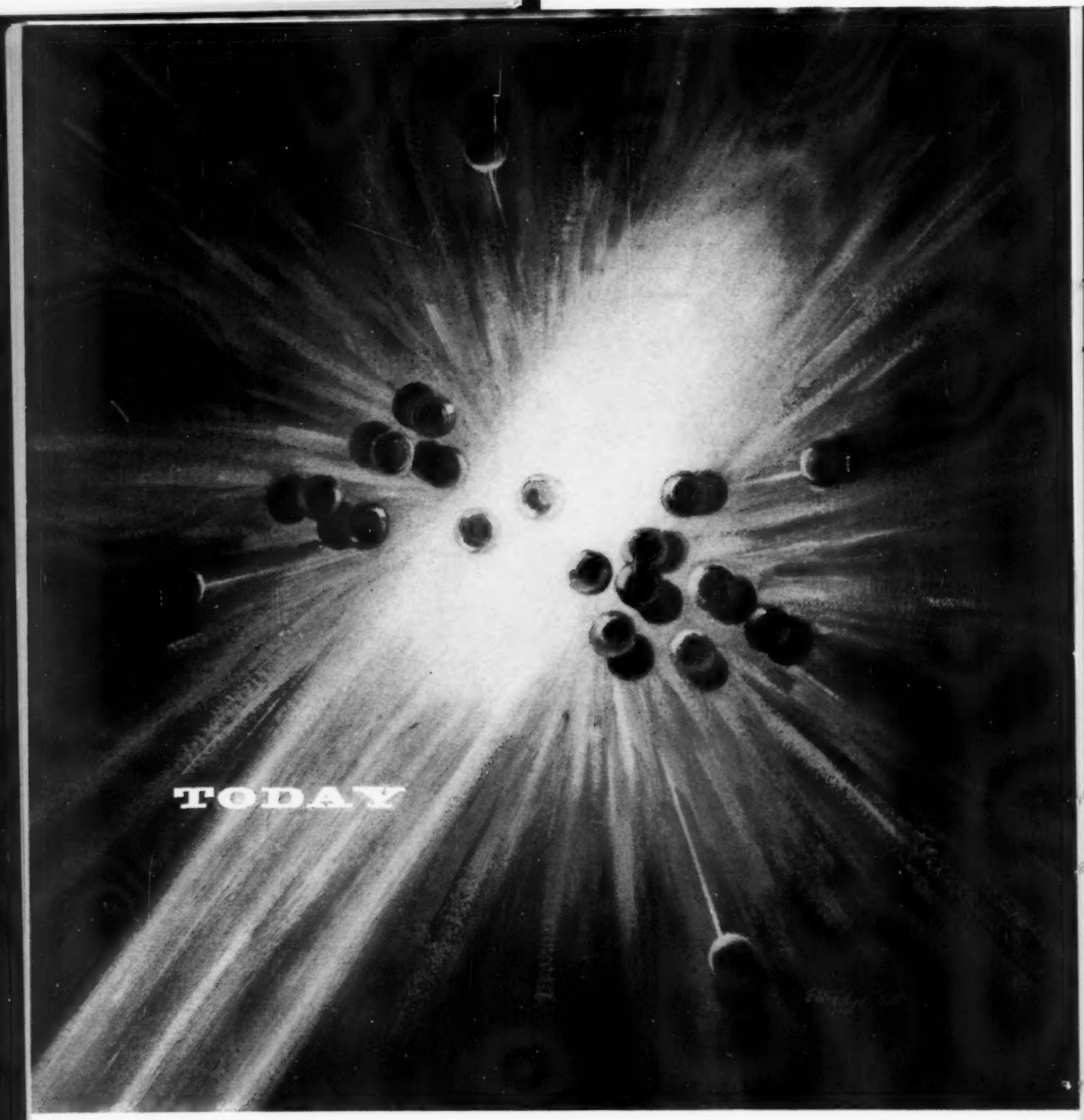

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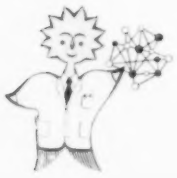

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